# Towards a Design Framework for Adaptable Reconfigurable Virtual Learning Environments

Michiel Nikolaas Smuts

A thesis submitted for the degree of PhD in Computer Science.

School of Computer Science and Electronic Engineering

University of Essex

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# Abstract

Technology is giving us new ways to interact with our world and this offers us unprecedented access to knowledge. To benefit from this access, we may need new ways to interact with subject matter, and it may be helpful to match the affordances of technology to the learning affordances of our minds. One possible approach to this problem is to leverage our natural environmental awareness. Humans are a successful species because we adapt so well to our environment, and adaptation is the focus of this research, which uses computer science to design a language teaching tool. The research is intended to further the development of virtual reality teaching environments by proposing a design framework created to manage changes in a virtual world. Subsequently, a virtual world based on the framework was created, and used to teach a language concept, the English preposition “over”. A serious game created on two platforms, one PC, and the other Virtual Reality, was used to deliver the teaching challenges based on the different meanings of the preposition, and tests before and after the use of the game were used to measure improvements in learning outcomes. The PC game had both an adaptive and static environment, and the VR game had an adaptive environment. The research found that the VR game resulted in the strongest effect on learning outcomes. The VR environment challenge which used a “sorting” mechanic resulted in a statistically significant change in test scores as did the “ordering” mechanic in the PC Static environment. Both had a medium effect on scores. The research also found that the actions taken inside the environments were not affected by profile differences such as age, gender, English proficiency, or role. The test scores for the meanings “Cover”, “Excess”, and “Temporal”, all showed improvement in post-test scores, however, the effect size was small, and not likely to be significant. Further study comparing Static VR platforms with adaptive VR platforms as well as mechanic-specific research is needed.

# Acknowledgements

I would like to thank my supervisors; Dr Aikaterini (Katerina) Bourazeri, Dr Adela Ganem Gutierrez, and Dr Michael Gardner, for their guidance, support, and patience over the last few years. I owe a huge debt to my wife Wendy for her patient listening, and unending support, and without whom the editing process would have been immeasurably difficult. This, and all my work is for my children, Abraham, George, Elsa, and Temperance.

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# Glossary

| Term | Description |
| --- | --- |
| 3D | Three Dimensional |
| Adaptive | The environment and items which change to guide the player |
| CL | Cognitive Linguistics |
| CP | Cognitive Psychology |
| DOF | Degrees of Freedom |
| L1 / L2 | L1 First Spoken Language, L2 Second Spoken Language |
| PC | Personal Computer |
| POV | Point of View |
| RFT | Relational Frame Theory |
| SCT | Social Cultural Theory |
| Static | The environment with no adaptive element and no feedback |
| VR | Virtual Reality |
| ZPD | Zone of Proximal Development |

# 1 Introduction

Technology is giving us new ways to interact with our world and this offers us access to knowledge previous generations would find hard to imagine. To benefit from this, we may need new ways to interact with the subject matter, and it may be helpful if we were able to match the affordances of technology to our natural innate learning approaches. One possible way to do this is to leverage our environmental awareness. Humans are a successful species because we adapt so well to our environment, and this adaptation is the focus of this research, which uses computer science to design a virtual reality language teaching tool. Language is our way of representing the world around us and is part of the many elements which help us represent our environment in our minds. This research employs quantitative methods through a controlled virtual environment, in an attempt to understand how changing our environment affects our representation of language. Computer science gives us the tools to both create an adaptive learning environment as well as measure learning outcomes affected by that environment, thus providing a new way of viewing language acquisition. By researching learning outcomes affected by adaptive environments, and attempting to measure which changes are statistically significant, this research intends to help in the development of new methods of passing on knowledge. As this type of research is fairly new (combining virtual reality with an adaptive environment focused on language), one way to place this research in context with the current literature, is to view it as an interdisciplinary synthesis of old problems and new technology approaches. For example, this application of virtual reality is an approach to behavioural change through what Fogg [1] describes as "…making desired outcomes easier to achieve", applied to second language acquisition. Arnab [2] writes of behavioural change " Naturally, video games are used to implement persuasive strategies by utilising the power of mechanics, and elements of the game design; for instance, self-monitoring, which can allow people to monitor themselves; conditioning, which offers rewards based on the performance of particular behaviour; and tunnelling, which is about leading players through a prearranged sequence of actions to either encourage or discourage particular behaviour". This description can in some ways be applied to the research, however, in comparison, this research looks for changes in understanding indicated by behaviour. It attempts to identify a measurable cognitive change in the understanding of a language concept, and further, that this new understanding can be enacted by the player producing a demonstration of that understanding.

## 1.1 Motivation for this Research

It is generally accepted in psychology that humans learn from their environment, [3] and that our experience creates our knowledge, and informs our behaviour in that environment. Although "experience" is difficult to define [3], cognitive neuroscience draws a distinction between the effect environmental experience has on behaviour, i.e. between a) habit, and b) goal-directed reinforcement learning [4], the latter of the two being arguably a focus of teaching, especially in second language acquisition as teachers seek to instil an understanding of language rather than a Skinnerian behavioural repetition of words [5]. Behaviourists hold that response to stimuli (classical conditioning), and reward or punishment for those responses (operant conditioning), are effective methods for teaching humans. However, this research holds that motivation and intellectual and emotional factors also play a role in determining whether learning takes place, and affect the substance of what is learnt [6], as do social and cultural factors. It is this concept of behavioural change driven by the environment which is the motivation for this research. The research uses a computer game to create an environment in which students experience change while attempting to learn. They are encouraged to engage with challenges which follow a simple narrative; abide by real-world physics rules and offer context for the lessons. Many educators and technologists propose that as game platforms become more immersive, realistic, and complex, offering an ever-closer fidelity to real life they may, in some instances, be able to replace traditional methods of teaching [5]. This research is an attempt to contribute to the development and design of such teaching environments.

## 1.2 Research Issues

With the advent of 3D environments came the possibility to programmatically change an environment whilst it was being used. This is a fairly recent development and allows the study of programmatic changes in participants' behaviour. Issues to consider when researching a real-time environment which changes in response to participants' actions are; what to measure, how to measure, and how to analyse those measurements in a way that relates to meaningful changes in the participant's behaviour. Consideration also needs to be given to the experimental conditions and the platform on which the 3D environment is built. This research uses both supervised and unsupervised experimental conditions as well as a PC platform which is essentially a flat screen and a virtual reality platform which is intended to be fully immersive. Creating a framework which combined measurement of behavioural changes with environmental changes. Furthermore, the context of the subject matter was one of the main challenges in this research.

## 1.3 Problem Statement

*If people learn to adapt their behaviour to suit their environment, can the environment be adapted to improve learning?*

To research the hypothesis that people can indeed learn more effectively from an adaptable environment, a game was designed to impart knowledge which included measurable and reproducible adaptations, so that any observed positive effects could be used in future generalised designs. This game was offered on 2 platforms and was the basis for the following 4 research questions (Table 1):

Table 1. Research Questions

| | |
|---|---|
| **Research Question 1** | Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of 'over'? |
| **Research Question 2** | Did interactions in the VR or PC game differ by the task? and if so, do those differences correlate to differences in performance or profile? |
| **Research Question 3** | Did performance vary by meaning or game mechanic? |
| **Research Question 4** | Did profile differences between students, factor in predicting performance in the VR or PC game? |

Working with an Applied Linguist (Co-Supervisor) from the University of Essex, Department of Language and Linguistics, a game was designed to teach an English preposition to students for whom English is a second language. English prepositions are particularly difficult for second/foreign (henceforth L2) language students to learn, they are often polysemic with many meanings attached to a word or phrase, and they rarely have direct equivalents in other languages [7]. For this research prepositions were particularly useful in that they are spatial in nature and ideal for a virtual environment which emulates real-world physics. Challenges based around English prepositions were built into the game in a way that encouraged the player to engage with the concept of the preposition. Serious games often attempt to increase or enhance player interaction by including narratives which encourage players to overcome obstacles and engage with challenges. This research relies on established theories of learning which suggest that participant interaction with the subject matter and their application of the knowledge affect learning [8, p. 293], [9], [10, p. 16]. In this case, the application of the knowledge is the successful demonstration of a preposition within the game showing that the participant has successfully internalised the concept. Successful demonstration requires the participant to understand the context within which the preposition exists, and this context is provided by the game, the theme and the narrative. Adapting an environment in which the player is already engaged with could be obtrusive, distracting, and uncomfortable for them, increasing cognitive load and reducing focus. The adaptations in the research game are therefore intended to be subtle. They aim to create feedback which provides guidance while remaining in context and is not overtly out of place in the game and the narrative. The control condition for the experiment is the absence of this feedback.

## 1.4 Chapter Structure and Summaries

The overarching aim of this thesis is to explore how environmental changes affect learning, by creating a design framework for conceptual learning and evaluating this framework on a PC-based platform. A Virtual Reality platform was the initial vehicle in which to test this theory however, due to the restrictions of the Covid 19 pandemic this proved impossible. However, serendipitously, the use of a PC-based platform as an alternative enabled the research to include a comparison between PC and VR learning platforms when restrictions were loosened.

This research is divided into 6 main sections (Figure 1).

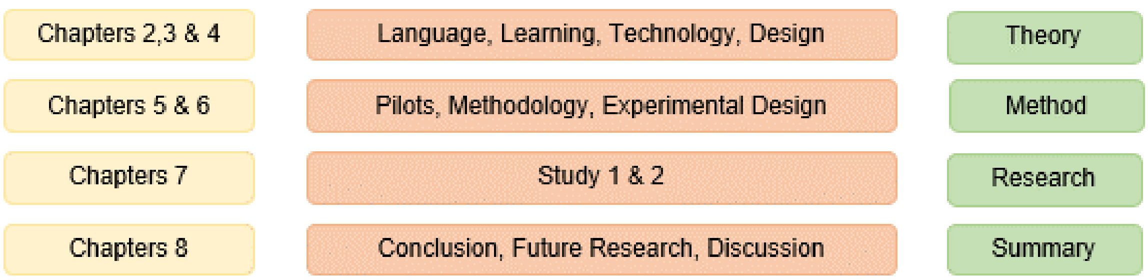


Figure 1. Thesis Structure

Chapters 2, 3 and 4 are concerned with the theory of learning, technology in learning and game design theory. They briefly describe the current literature on knowledge, language, and learning, as well as the addition of technology to the learning process the design of the platform and the implementation of the design framework within the platform.

Chapters 5 and 6 describe the design, creation and testing of the VR and PC platforms, as well as a description of the experimental design and implementation during COVID. These sections also include descriptions of the variables which were used to answer the research questions as well as where and how the variable data was collected.

Chapter 7 describes the PC study and the VR study. It provides a statistical analysis of the results as well as a discussion and interpretation of that analysis.

Chapter 8 summarises the findings from the two studies, and suggests future studies and discussion is the implications of the findings as well as some interpretations based on anecdotal evidence.

## 1.5 Publications arising from this thesis

**CEEC 2019: 11th Computer Science & Electronic Engineering Conference.**

"Towards Dynamically Adaptable Immersive Spaces for Learning"

A "work-in-progress" paper describing a model for cloning behaviour to teach adaptable environments using machine learning agents.

**TALE20: International Conference on Engineering, Technology and Education**

"Interdisciplinary Research Towards Creating a Design Framework for Adaptable Virtual Learning Environments"

A "work-in-progress" paper describing a framework for building Virtual Reality worlds for teaching

# 2 Theoretical Foundation: Literature Review

## 2.1 Introduction

This research deals with knowledge in two complementary ways. The research itself may be considered inductive, attempting to generalise from specific observed results, i.e., investigating the effectiveness of an approach and materials for helping L2 learners acquire the various senses of over, through controlled experimentation. However, central to the research is the idea that knowledge, and the acquisition of knowledge related to language, can be inferred from an environment and therefore it is deductive as it implies specific conclusions from generalised events. The inductive approach is straightforward in that the participant's knowledge is tested before and after the use of the environment and a conclusion is drawn. The deductive approach however is more complex as how the transfer of knowledge from the environment occurs is based on multiple theories. Firstly, the teaching environment (the game) the participant experiences is not the only factor which will affect the results of the experiment. The environment represents a scene which should be familiar to the participant, i.e., a desert island, a bridge, and a challenge. These are iconographic and should already be represented internally by the participants' existing knowledge [11] i.e. cognitive structures already created by their first language (L1). Here it is intended that the participant incorporates the second language's structure and meaning into their first language structures instead of, for example building a new system of understanding, a process described by Paiget [12] as assimilation. Secondly, the research takes the constructivists view that cognitive structures are flexible with the ability to adapt without new information and that an existing cognitive structure may guide what a participant pays attention to and what they choose to learn [13, p. 17], [14, p. 30]. Thirdly, it takes an empiricist view of knowledge acquisition in that language is a way to interact, understand, and describe the world. As a result, the participant's embodied experience of the world is central to that experience, i.e. where they are in relation to the objects they interact with. The participant is in effect part of, not isolated from, the language and the world from which it derives meaning [15, p. 44], [16], [17, p. 93]. Whilst it could be argued that a participant's first language is a representation of innate knowledge and therefore rationalist in nature, the researcher takes the view that the first language represents a record of experiences, what David Hume described as prior impressions [18], and that any change in the participant's ability to understand the second language could reasonably be considered new knowledge.

# Part I

## 2.2 Learning Theories

This section is intended to describe learning theories as they relate to the problem definition for this research. The objective is to align compatible learning theories with the research approach used to answer the question "can an adaptive environment affect learning outcomes?". Research into environmental effects on learning needs to be grounded in a theory which supports the idea that learning can be affected by the environment. While on the surface behaviouralism may seem to support such a premise, where language is concerned, humans need to create conceptual structures of meaning and this creation is difficult to understand through the lens of behaviouralism alone. This is because repetition without understanding does not easily lead to using new knowledge in new and dynamic situations. Essentially language requires context and context is created in the mind while making sense of environmental interactions and storing them as models for future situations. If interacting within a VR or PC environment can create a model of understanding in the participants' minds these models may then be able to be applied to the real world after the teaching has been completed.

## 2.3 Cognitive Learning Theory

Cognitivism emerged in the 1960s as an alternative to behaviourism and forms the origins of cognitive psychology and cognitive linguistics (Figure 2). It is concerned with how people create meaning from new information and regards behaviour as the result of a mental process [17] rather than the reaction to stimulus. In effect learning which mediates behaviour is a secondary result for cognitive learning theory as "learning" need not change behaviour, while it explicitly changes mental processes. This thesis distinguishes between an environmental change which enhances meaning (Cognitivism) and an environmental change which creates a stimulus resulting in a response which changes behaviour (Behaviourism). Specifically, the research emphasises language as a form of regulation for the participant to conceptualise their actions within their environment.

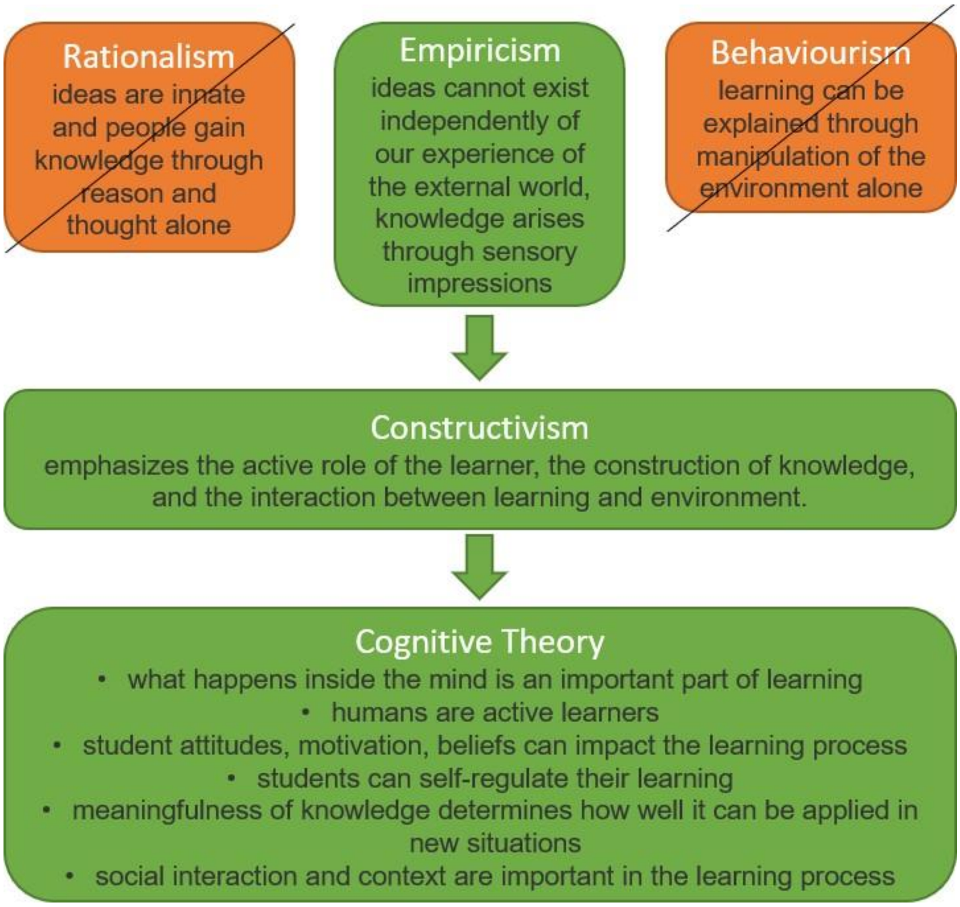


Figure 2. Learning Theory[19]

This research applies Cognitive Learning Theory (CLT), which suggests that people learn from their environment, from what they see, how they interact, and from the consequences of their actions [20], [17], [21]. It also relies on Cognitive Linguistics (CL) which seeks to expand the understanding of meaning creation by accounting for human psychology, CL is an interdisciplinary approach to understanding language as part of human cognition (Figure 3) [22]. Unlike Cognitive Psychology (CP)[19], Cognitive Linguistics embraces human encounters with the world and considers interaction an important part of language acquisition. The psychologist Vygotsky saw the activity of co-construction as key to pedagogy, moving away from knowledge previously formulated by others to knowledge with meaning negotiated with others. Therefore, Vygotsky disagrees with a more cognitivist view which sees knowledge as appearing first in the individuals' mind and then using that knowledge in the social plane, for interaction, communication, etc. This Vygotskian view that meaning is constructed also points to a "socially scaffolded development" [23] of language skills involving action-reaction and feedback. Cognitive learning theory as mentioned above, emphasises the importance of a range of inputs which influence learners and is in keeping with Vygotsky [24] and Leontievs' [24], [25, p. 362] view that "real life" is a key factor in the pedagogical development of the mind. From this standpoint, Leontiev differed slightly from Vygotsky who focused on the tools of learning rather than the activity, motive and purpose of the experience [24]. While Leontiev favoured a focus on activity, he also (along with Vygotsky) emphasised micro genetic (appropriation and internalisation of language through social interaction [26, p. 231]), ontogenetic (the way language adapts as it is acquired [8, pp. 4, 520]) and phylogenetic (the way language adapts to sociocultural environments [27, p. 24]) development. This could be considered an Empiricist point of view which sees knowledge resulting from interaction with the world rather than the idea that knowledge is innate (Rationalist). The demarcation lines between psychological theories of learning can be difficult to discern as behaviourists tend to be empiricists (Locke, Hume) and cognitivists (in psychology) tend to be rationalist (Kant, Descartes) [19] however, CL while interested in the mental processes which create meaning, embrace the empiricists view and attribute importance to embodied experience [15]. The unified experience of mind and body interacting in the world (embodied action) forms an essential part of the creation of higher-level cognitive skills such as reasoning [15].

Further, the research focuses on English prepositions which are often polysemic with multiple meanings attached to a word or phrase. These meanings are not random but reflect a network of related but unique meanings which in turn reflect the human experience of them. This semantic network is theorised to be organised around a primary (proto) meaning and reflect conceptual structures already created from experiences in the world [28].

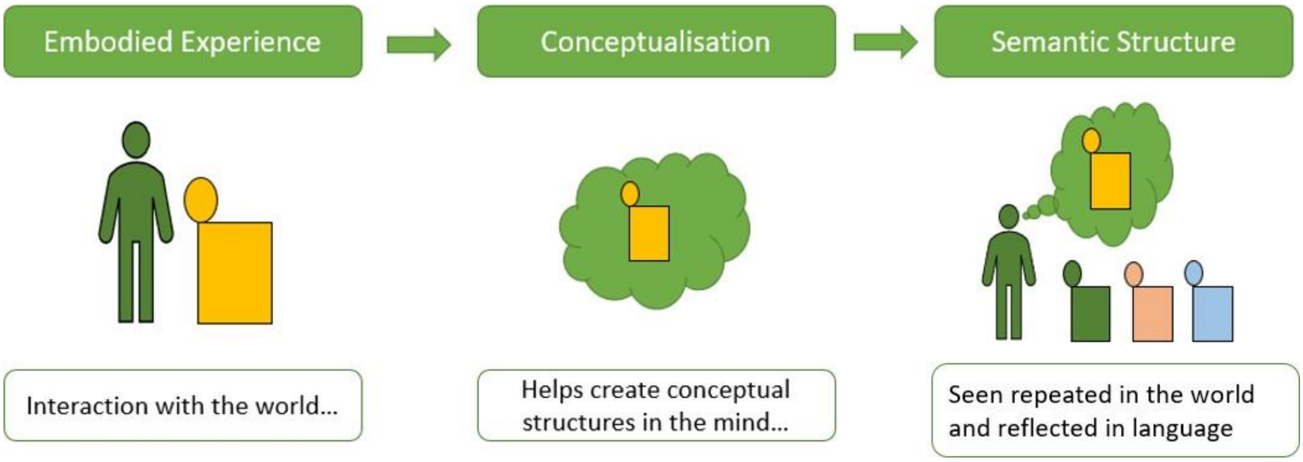


Figure 3. Cognitive Linguistic Framework

## 2.4 Gestalt and Cognitive Linguistics

In the Gestalt theory of perception [29, p. 87], [30] items, objects, and experiences are grouped. Grouping can be associated with movement, i.e., items which move together are grouped such to colour, shape and proximity. This grouping is a process which helps us make sense of the world around us and informs our interactions and experiences. Grouping is said to be perceived spatially rather than in a flat visual array [31] (i.e., in 3D rather than 2D). In the Gestalt image schema, the brain, body, and physical environment, act together to create a grouping of our surroundings. Gestalt psychologists also describe the experiential processes through which we convert actions into an understanding of abstract concepts [18, p. 69]. The physical sensations of interacting with our environment help us create an "image schema" first described by Metzger [32], and applied to linguistics by Lakoff [33] where we and the objects around us are ordered in an imaginary relationship with each other (another form of grouping). This is described by the cognitive linguist Talmy [31] where he identifies a difference between the "figure" in a scene and the "ground" element against which that figure should be viewed, essentially "grouping by proximity follows a gestalt perceptual principle" [22]. However, as Kreitzer [34] points out many senses (meanings) of a preposition represent the unfolding scene and so are dynamic, rather than static. His example is the comparison of these two sentences; 1) I walked over the field; 2) I walked over the field to reach the house. Two distinct senses of the preposition “over” are defined by the unfolding scene. According to Tyler and Evans [27], “over” has 14 different senses (Figure 4) all of which require context for accurate interpretation. This research adopts this polysemic network of “over” [28], [35], [36], using the idea that the meanings are linked and dynamic and creates challenges consistent with the Gestalt theory that experiential processes convert actions into an understanding of abstract concepts. Essentially, if prepositions are not experienced as an unfolding context, they can be particularly challenging for L2 learners.

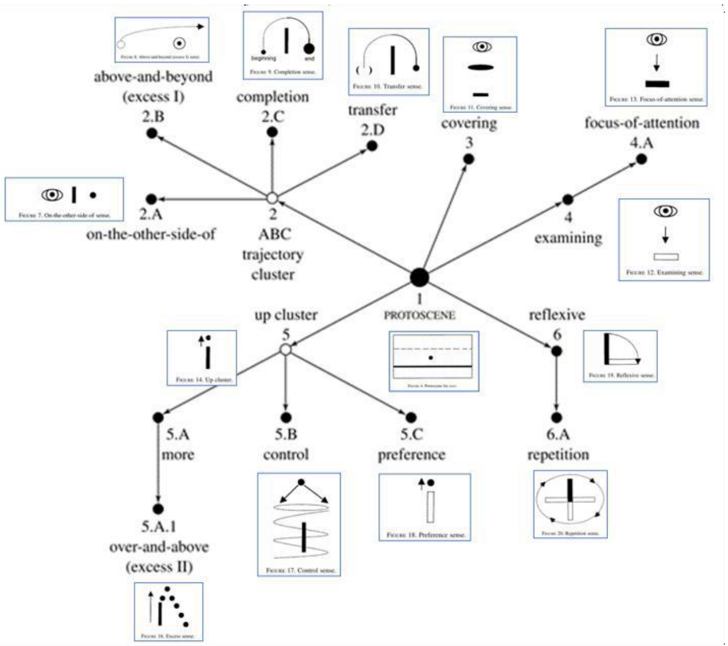


Figure 4. Semantic Network for "over" adapted from (Tyler & Evans, 2003)

## 2.5 Proprioception, Embodiment, Enaction

To conceptualise our world, we create a mental schema as described in Figure 3 and to do this we require a perspective which naturally is personal to us and relative to our position in the world. The feeling and awareness we have of the position of our body in the world (proprioception) help to shape our schema, which in turn shapes our conceptual understanding, i.e. we see and understand the world from our point of view [37]. Phenomenologically the way we experience the world around us and how it changes, when we interact with it, is explained by cognitive linguistics (CL) as the embodiment of language concepts, i.e. the combination of speech, gesture, and interaction, and is an important part of making sense of the world or creating meaning. CL uses a symbolic system of spatial reference to create a hierarchy of objects when describing prepositions [27, p. 12]. This system defines which items are to be compared, based on spatial position and context. For example: in the context of a hummingbird hovering over a flower, the hummingbird is the focus of our attention and considered the trajector. Its ongoing actions are measured against the flower, which is considered the landmark, and in this way, the context of the unfolding scene helps the observer identify which preposition to use. This is consistent with the gestalt idea of "figure" and "ground". From a theoretical point of view, this research relies on the concepts of proprioception and embodiment and their role in cognitive linguistics as justification for the design framework and the environments used to test it. The expectation in the hypothesis that the environment will lead to a greater understanding of conceptual language rests on the grouping of correct and incorrect items based on their context, the similar movements of those items which reinforce those groupings and the position of the participants. It also depends on the participant's interaction with the environment. As previously mentioned, speech, gesture, and interaction are part of CL theory. In support of the cognitive approach, dynamic interaction between actors in an environment (Enaction) has been shown in cognitive psychology to enhance memory [38], [23, p. 304]. This dynamic interaction is demonstrated in the research environments challenges where items respond to their position and the environment itself responds to changes. A small learn, practice, master loop (also known as the interaction loop) [39, p. 260], is also included in the challenges where each of the tasks must be repeated correctly four times. This is intended to act as conceptual reinforcement where the demonstration of the concept is enacted by the participant more than once. This is not an attempt to create a conditioned reflex associated with Pavlov, Watson, Thorndike, Skinner and Bandura et al [40], [41], a common form of habit formation in the classroom since the 1920s. The behaviourist approach to repetitive processes as a method to create high-fidelity reproductions of "knowledge" or performance says little about the internal processes which establish meaning in the learner's mind. Rather, as CL sees cognitive processes and language as linked these repeated tasks are an opportunity for the participant to experience and interpret the sense.

## 2.6 Contrary Theories

This research applies cognitive learning theory (CLT), which suggests that people learn from their environment, from what they see, how they interact, and from the consequences of their actions [42][39], [43], [3]. It is also informed by sociocultural theory (SCT) and the ideas of Leontiev who suggests that "real life", a short phrase which describes his belief that internal mental processes created by external interactions retain their relationship after the activity has ceased, is a key factor in the development of the mind [24], [25, p. 362], and those of Galperin who suggests that "materialised actions (using models, simulations, animations, schemes)" [24] are necessary to create new types of internal psychological activity. It relies on Galperin's extension of Vygotsky's "Zone of Proximal Development" (ZPD) to include the interaction between teacher and learner and the creation of activities which support the psychological transfer of external activity to internal conceptual understanding [24] i.e. meaning-making through activity. There may be a link between the SCT lens of mediation (a bi-directional social interaction to negotiate to mean) and the relationship between the participant in this research and the adaptive environment, i.e., the feedback given by the environment could represent a simple form of mediation. Learning in adaptive VR is also possibly consistent with constructionist cognitive learning theorists who explain the acquisition of knowledge as the result of inductive learning (generalisation from examples) as proposed by Carroll [44].

The research attempts to avoid applying behaviourist theory by making the solution to each challenge different while using the same icons, objects and processes in the execution of the challenges. While there are several theories specific to the acquisition of language, ranging from those who suggest that language is a manifestation of the more general skill of symbolic representation like Piaget or Skinner

[27], and those who consider language too complex to be learnt from environmental exposure, like Chomsky [45, p. 44], this research adopts a contrary position to the coherence principle [46] [47] and cognitive load theory [48][49]–[51] which suggests that people learn more effectively when not distracted by extraneous factors. In fact, in attempting to create a facsimile of real life the research adds

noise in the form of the sound of the wind and background elements such as colour in the use of day-night cycles and background objects and movement. Noise, colour, and movement are used as feedback both negative and positive following participant actions. There is a natural conflict between an immersive environment and a focused teaching environment and attempts to reproduce the "messy world" which is real. These issues are addressed further in chapter 4 page 24.

## 2.7 Second Language Acquisition

General learning theories compared to language learning theories differ in the way they propose and theorise learners process information. Most general learning theories favour the acquisition and application of rigid rules of meaning which can be applied in a definitive correct or incorrect manner. In Linguistics it is common to apply meaning to symbols, studying what can be understood from the application of knowledge (in this instance, words and grammar) in a more dynamic context. Cognitive Linguistics (CL) incorporates theories of meaning, linguistic organisation, learning and conceptual structure. Under this umbrella, Universal Grammar (UG) Theory and Autonomous Induction Theory (AIT) are mostly rejected in favour of general learning mechanisms [49] which suggest that humans conceptualise meaning through their embodied experience of the world. Cognitive Grammar (CG), a theory within CL, suggests that meaning is held in symbolic units rather than a system of rules. The research environment attempts to align with CL by treating every item or object as a symbolic unit with dynamic meaning based on activity or context.

## 2.7.1. English Prepositions

L2 learners often have specific difficulties understanding the use of English prepositions (2. 4) [52]–[56]. Linguists and psychologists have explained the difficulties by describing several contributing factors, for example, 1) Native grammar (L1), knowledge conflict with L2 rules [57, p. 4]. 2) English prepositions are syntactically idiosyncratic, rarely following a predictable pattern [58], 3) Many prepositions are semantically polysemic resulting in multiple meanings dictated by context [7, p. 445]. 4) Often the preposition will not contribute substantially to the meaning of the sentence compared to (incorrect) alternatives [58, p. 196]. 5) Morphologically prepositions are difficult to recognise as they can contain few syllables and can be difficult to identify in speech [58]. 6) L1 languages may have no direct translation for the L2 preposition [59]. 7) Cultural lexical priming can create confusion when community traditions defining semantic associations differ substantially from English semantic associations [60, p. 55]. 8) Structural priming (where L2 speakers repeat the structure of the sentence heard previously), can be confusingly incorrect as prepositions are syntactically idiosyncratic as previously noted in item 2 [61]. As well as presenting a learning challenge prepositions are notoriously difficult to teach [7], [58], [62]. Tyler & Evans [35], note that some traditional teaching approaches emphasise core meanings of prepositions rather than their abstract meanings, leaving most of the meaning untaught. English prepositions are extremely polysemic in their use outside of their core meaning and purpose, yet they often have very little pragmatic meaning compared to the rest of the sentences they are used in. This polysemy is context sensitive, making them uniquely difficult for second language learners to grasp through traditional rote teaching. When the differences in meaning are seen as idiosyncratic variations which must be committed to memory, the process of learning them seems more difficult than if the difference simply represents a new level of conceptual organisation as described by Lakoff [33]. A PC/VR-based platform for teaching allows two clear advantages: the ability to conceptualise the spatial experience required to understand the symbolic meaning of prepositions, and the ability to enact changes to the environment unique to the learner in a seemingly physical manner.

# Part II

# 3 Learning Mediated by Digital Devices

## 3.1 Summary

This section discusses the role of digital devices as a substitute for real-life experiences. While learning theories describe the role of interaction, experience, and feedback in the real world during the acquisition and application of new knowledge, it is important to recognise and describe the differences between these real-world experiences and the platforms on which games, which simulate those experiences, are developed. In this research the expectation that the learning behaviour adapted by an environment can be simulated by a PC or VR environment is central. In effect, there are three worlds to consider, the real world where change is intended to be enacted, the PC environment, and the virtual reality environment. The game environments are intended to provide a similar problem-solving situation to the real world and act as learning agents providing a safe space for the participant to experience success and failure. This section explores the limitations and advantages of these environments as well as discusses the methods for interaction used by the participants. Where possible the challenges and interactions of the games are the same on both platforms, however, the user experience on each platform may differ and this may affect the learning outcomes of the different groups.

## 3.2 Game Environment Formats

The most common format for educational games is the desktop version with the familiar flat-screen keyboard and mouse. Less common is the virtual reality (VR) version with a headset and hand controls. This research uses the same game created on both platforms (Figure 5).

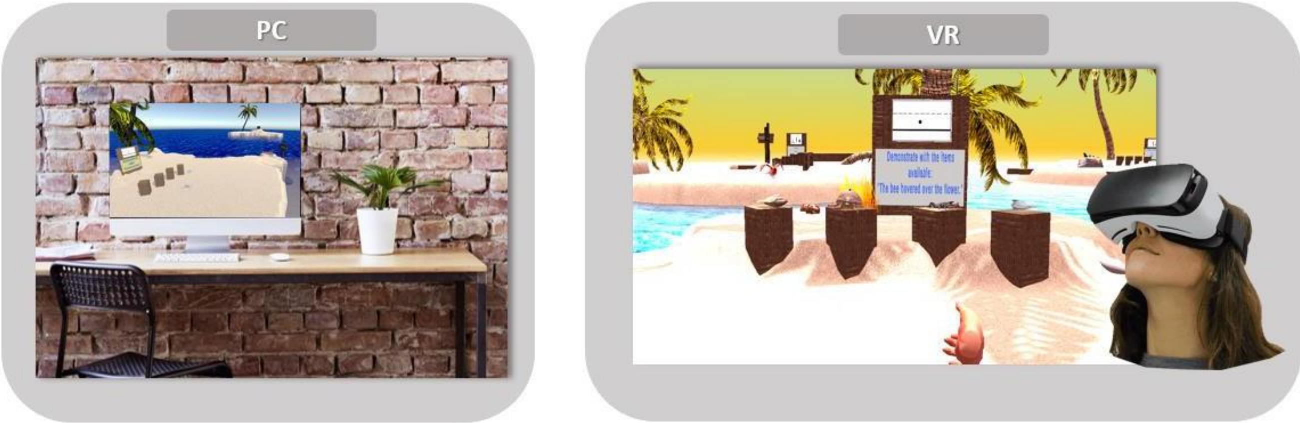


Figure 5. PC and VR Environments

## 3.3 Immersive & Adaptive Learning Environments

Schrader [63], defines immersive learning environments as the difference between learning “with” technology and learning “in” technology, and emphasizes cognitive engagement consistent with the description of cognitive linguistics as described in section 2. 4. He suggests that when a user’s actions within virtual spaces are inseparable from their cognition, then they are functioning, learning, and interacting, within the technology. Jennett et al [64] in their attempt to quantify immersion suggest that players’ level of absorption in a game, their engagement and the extent to which they are in a state of flow (a psychological state where the player experiences the game aesthetics) (Figure 25), excluding external stimuli, may all be points on a scale of immersion. However, they draw a distinction between flow which requires the player to have an understanding of goals and immersion which does not. In this research goals and therefore flow is important as is immersion. Player focus, their sense of challenge and their disassociation with the real world [ibid] are considered necessary tools for creating a learning environment which is consistent with cognitive linguistics theory. As such, the Virtual Reality (VR) version of the game which uses the Virtual Reality head and hand set known as Oculus (a headset worn by the participant which gives a 3D experience) (Figure 6), is more likely to create an immersive experience than the PC game which operates in a screen based, 2D form. The game developed for the Oculus aimed to mimic real life by translating head and hand movements made in real life into the virtual environment, therefore offering some of the cognitive benefits to learning described in section 2. 4. Also, the tasks were designed to support the hypothesis that “materialised actions” (section 2. 6) will improve conceptual understanding and as a result improve learning outcomes. Immersion is intended to encourage a user to engage with the game by integrating the environment, its context, the narrative, and the objectives of the game so that the participant can have meaningful interaction within it [65]–[67]. The design and implementation of such principles in this research are described in Chapter 4. Immersion is most apparent in virtual reality where the cognitive engagement of the player with their environment is close to a realistic representation of the world. Movements and actions provide an element of representational fidelity and support embodied experiences.

Dalgarno & Lee [68], in their paper discussing the learning affordances offered by 3D environments, suggest some defining characteristics (Table 2). See also [69]–[72].

Table 2. Distinguishing characteristics of 3D Environments [68]

| Category | Characteristic |
|---|---|
| Representational fidelity | Realistic display of the environment |
| | Smooth display of view changes and object motion |
| | Consistency of object behaviour |
| | User Representation |
| | Spatial audio |
| | Kinesthetic and tactile force feedback |
| Learner interaction | Embodied actions including view control, navigation and object manipulation |
| | Embodied verbal and non-verbal communication |
| | Control of environment attributes and behaviour |
| | Construction of objects and scripting of object behaviours |

Interactive technology is becoming a natural part of our everyday lives, and its use in education is already ubiquitous. However, VR platforms represent only 29% of the console market [73], and educational VR games are still relatively novel. Dalgarno & Lee [68] suggest that VR's immersive qualities appear to be superior to screen-based alternatives as the haptics (hand movements) are more natural to the participant, less obtrusive and therefore less distracting. When learning technology is no longer at the forefront of a participant's perception, whether it is accepted as an extension of normal life, or as a natural actor in a learning environment, it is "ambient" and empowered by its invisibility. This is because the adjustments or contributions it makes to the learning process go unchallenged in the participant cognition [74]–[76]. Augusto et al [75], describe ambient intelligence as "assisting in a sensible way" [77], implying that the environment can recognise when it is allowed or appropriate to help, and it does this automatically without external intervention. Augusto et al [Ibid], generally describe physical systems and specify that ambient intelligence as a principle should not adjust the appearance and atmosphere of the environment. This research diverges from Augusto in that the research platform not only adjusts the "appearance and atmosphere" but in some cases actively attempts to be more visible. Given the current acceptance of technology in daily life, it may be possible that participants will accept the environmental changes as a natural actor in the learning process. Participant acceptance could be further challenged by the use of positive and negative feedback loops guiding participants through diegetic changes, i.e., the more overt the changes the more the game relies on the participant's acceptance of interaction which is manifestly not consistent with the real world. This apparent contradiction might be addressed in the design of Intelligent Tutor Systems [78], [79], [80, p. 12]. Intelligent Tutor Systems (ITS) and Intelligent Learning Environments (ILE), i.e. those which adapt to the learning context, participants, and available material [81], deploy a range of approaches to tailor the knowledge to participant ability. For example, adaptive workflows [82], pro-active queue management systems [83], semantically adaptive web-based systems [83], and artificial control systems for simulated humans [84]. These approaches all deploy a collection of reusable activities known as learning objects (LO) and an element of contextual matching between participant and material. ILEs predominantly use past performance combined with LO, to identify participant learning needs and adapt accordingly. This research adopted some of these approaches to make the environmental changes less overt; for example, extending the narrative or repeating LOs. These changes are consistent with an adaptive learning environment, although it could be argued that they change a central feature of that environment i.e., the environment itself, rather than the physical interactional objects. This could be considered a divergence from the cognitivist view that interaction, in this case, the interaction with objects within the environment, is a way for L2 learners to verbally engage with mediators [25, p. 391]. These mediators are normally teachers or peers helping to co-construct the language and represent what cognitivists see as the social nature of language development, however, in this case, the mediators are the feedback mechanisms in the environment.

User-centric models which focus on the learning needs of the participant, such as Augusto's [88] adaptation of learning environments for children with special needs, and Yang's [21, p. 24] summary of e-Learning characteristics, vary in their approach to adaptability. This variation ranges from the participant choosing the learning material to the environment effectively choosing the learning material based on the perceived needs of the participant. In this research, the entire platform adapts to the participant interaction. This fixed approach enables the environment to change quickly in real-time because it is not attempting to learn from the participant currently participating but from an already programmed blueprint. There may be a relationship between specific profile traits of participants such as gender or age, and comfort with or attitude for interacting with computers in a learning environment and this is taken into account in the analysis (see section 8. 7).

## 3.4 Learning Mediated by Virtual Reality

Virtual reality (VR) is a representation of a digital world in 3D seen through a head-mounted display (HMD) worn by the participant and interacted with through handsets or virtual hands which mimic the effects of real-life interaction (Figure 6). It gives the user the impression that the world they see is real and it allows the user to interact with that world according to what appears to be real-world physics.

Figure 6. Oculus Rift: Example of VR headset and handsets.

If a virtual world is designed in such a way as to convince the user that it is real, has substance and represents a meaningful interactable environment, it is considered to be immersive [43], [68], [72] and could be said to portray a manifestation of a conceptual structure. Because VR is a “designed” world, it represents a conceptualised view of the designer’s impression of the world. Cognitive Linguistics (CL), which focuses on the mental processes which create meaning and function in language, is ecologically consistent with a VR learning environment as VR can represent meaning without being restricted by reality, in the same way as the mind can create conceptual meaning [16]. The affordance of VR i.e. its ability to represent an immersive world encompassing user actions and consequences aligns with the arguments that favour the idea that exposure to environmental factors is crucial in the process of language acquisition and more specifically Cognitive Linguistic theories. As mentioned in section 2. 5, VR also reinforces Embodiment (our perception of ourselves at the centre of the world) and encourages interaction which is described by Enaction theory as helping the participant to understand and learn from their tasks [21]. Hazelden [15], in her discussion on Enaction theory, suggests that human cognition is interactive and meaning construction comes from our interactions with the world around us. This view combined with the affordances of VR is represented by Figure 7.

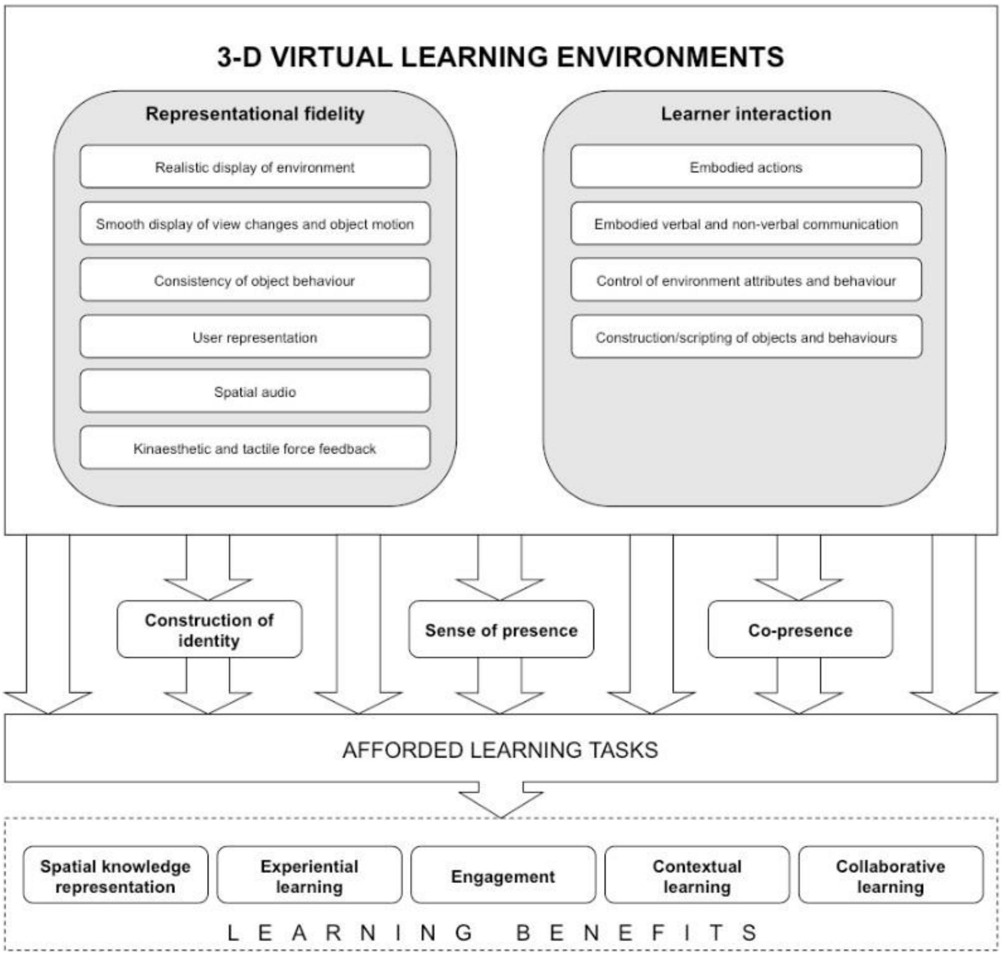


Figure 7. Elaborated Model of Learning in Virtual Environments [59]

By establishing a framework for environmental changes and building a VR world based on that framework, this research empirically measures the effects of VR on participant learning outcomes and compares these with screen-based copies of the environments as described in section 8.

Because in VR the participant is immersed and centred in their virtual world there is a seemingly natural relationship between their apparent sensory experience and the conceptual structures around them, in effect, the conceptual structure is embodied. We are all in effect immersed in a world of language, constantly deriving meaning, and co-constructing meaning with others [35], [89]. Interacting with immersive virtual worlds is ecologically consistent with real-world engagement and in turn with active learning strategies and the Interaction Hypothesis of second language acquisition [89]–[91].

The Interaction Hypothesis is concerned with how participants negotiate meaning through discourse. The participant is seen as active learner using information, they already carry with them from their own experience to interact with their world which agrees with CL which acknowledges the importance of motivation, beliefs, context, meaningfulness, and social interaction to the learning processes.

It is widely understood that comprehensible and appropriately contextualized second language input is necessary for learning to take place [92, p. 164], and the ability to provide a context in a virtual world should prove beneficial in teaching a second language as long as the design matches the users' interpretation of it. For example, in VR there are two sets of conceptual structures at play i.e., there are two points of view interpreting the virtual world. One is the designed world, primarily the world as it was intended to be with the afforded actions which were intended for the user. The other is what the user sees and constructs in their mind i.e., the cognitive semantic version of conceptual structures. This includes how the user with all their experience and understanding creates linguistic meaning [16]. VR supports embodied cognition because it allows interaction with the world [7, p. 452], [15, p. 27], [93, p. 157], permitting existing mental schemas of bodily experience to be overlaid onto the virtual world. VR is further able to reinforce the users' experience of the consequences of their actions in a virtual world by utilising both negative and positive feedback. For example, the concept of "overnight" is a representation of the passing of time, and in VR the day/night cycle can be accelerated so that night passes more quickly, in this way the participant can experience the consequences of their actions, learn from them and move forward. The day/night cycle can be accelerated so that feedback is immediate, and consequences are more easily linked to actions, thus giving the user an embodied experience, which resembles real life while the concept of "overnight", although artificially accelerated, maintains its meaning. Using the affordances of VR for representing concepts it is possible to apply the environment to teaching English prepositions to L2 language participants.

Contextualised tasks within VR can also be used to address sociocultural factors in language acquisition, and context is of central importance when combining VR design elements for a learning environment. For example; embodied action on a meaningful task requires context (or theme) to prioritize elements within the world [25] and to help the participant to predict the consequences of their actions. Their predictions will be based on their sociocultural interpretation of the world and the mental prototypes they have available to them (Prototypes constitute mental representations [94]). Context and feedback are core elements of the motivational system (see Modality in 4. 8) within a VR learning environment as they attempt to drive understanding by offering the opportunity to repeat the challenge several times. While this may seem on the surface as behaviourism, the complexity of interactions with tasks and feedback systems goes beyond stimuli and response and relate to the mental processes creating meaning through sensory interaction with the (virtual) world.

# Part III

# 4 Game Design

## 4.1 Introduction

A serious game intended to teach the preposition “over” was created on two platforms, PC and VR. The game consisted of twelve desert islands and the objective of the player was to move to every island in turn by completing physical challenges with the objects provided on each island. The learning goal was to understand how to correctly use the objects on the island i.e., demonstrating the correct form of the preposition (chapter 4. 3).

The PC game had two states: Adaptive and Static, the VR game only had an adaptive state. Adaptive describes an environment in which the items the player can interact with, turn to face them if they are the correct choice for the challenge, and turn away from them if they are incorrect (chapter 4. 9, chapter 4. 12). This is not explained to the player, it is inherent in the game. When the player makes an incorrect choice in the adaptive environment the atmosphere changes, e.g., the wind increases, the day-night cycle starts, and changes the scene to night-time and the sounds of a more disturbing environment increase in volume (Chapter 4. 12). Essentially, the adaptive state resulted in the game adapting to the actions of the player by giving feedback through changes in the environment, the Static state did not provide feedback. The game itself presents the player with different challenges which reinforce the different meanings of “over” in a specific context. During this research, the COVID pandemic restricted in-person research and so the PC version was developed as a remote challenge and emailed to participants. This necessitated specific additions for the PC game such as a tutorial, written instructions, and email technical support.

This section describes how the game was created, the design elements it contains and the reasoning dictating design choices. An environment which is designed to improve learning outcomes needs to be able to engage the participants so that they remain focused on the learning tasks and willingly interact with the environment. When it was reasonably possible to measure the difference between the game platforms and their associated learning outcomes, it was important to prevent differences in the game itself, its feedback mechanisms, and how it represented interactions, from becoming contributing factors. The variation in cultural backgrounds, age of participants, and experience with computer gaming also had to be taken into account as, if the game was too complex it could affect participants disproportionately. For this reason, the game was deliberately basic so that the participants who experienced the game differently on different platforms, were essentially solving the same problems in the same way, with the same forward-moving linear narrative.

Creating an environment which fosters learning in a world of rapid change, and ever-higher participant expectations could be considered the teaching challenge of our time [95]. Games provide experiences with which we choose to engage. They are voluntary, personal (though not necessarily individually experienced), and necessarily challenging if they are to be considered a genuine serious game [39], [96]. Serious computer games and pedagogy could be considered associated, as they both attempt to convey meaning through experiential and problem-based learning. In this research, the game platform itself replaces the teacher as facilitator and provides a framework to guide the participant through the learning process, while at the same time the participant retains some agency and is responsible for their progress [97]. Unlike a simulation or presentation where the participant is passive, this platform requires participant interaction, and in the adaptive version (only) it actively provides positive and negative feedback depending on the level of the participant's success. While the theoretical basis of the learning process incorporated into the game's design is closely aligned with operant conditioning, it goes beyond the behaviourist stimuli and reward or punishment scenario [98] as described in section 2. 4. Motivational processes which affect learning are thought to be influenced by cognitive mediators which utilise participant interpretations of situations and events [99], (this view aligns with cognitive interaction theory). When a participant pursues goals through a cognitive task they are said to be motivated by achievement [4], [99]. In the adaptive version of this research, as far as possible, feedback i.e.' rewards or punishments, is provided primarily through environmental changes. These are not proximal (in most cases), and the consequences for failure are primarily the failure to move forward (loss aversion), as opposed to the use of an aversive stimulus [42].

The research platform as with most serious computer games is goal-oriented, focused on gaining and keeping the participant's attention, and on motivating participants to progress. These attributes could all be considered method rather than theory-based approaches [97], and as a result, the implementation of game-based methods need not invalidate the pedogeological theory underpinning the platform design. Kirkpatrick [100], suggests four levels for evaluating teaching programs which may help appraise the game-based learning environments. Level one examines the reaction of the participant to, or satisfaction with, the learning platform. Level two measures the change in the participant's competence i.e., did the training increase the participant's ability (included in this research as a quantitative pre and post-test). Level three is focused on the transfer of behavioural changes in the participant i.e., do they implement their new skills after the training. Level four suggests measuring the results or benefits to the participant, which might be considered in this research as improved esteem and confidence, increased engagement with the language, and increased opportunities resulting from competence. Both levels three and four would require a time-delayed questionnaire, would be qualitative and are not included in this research.

Throughout this section, game use and learning environments have been discussed as if they are equally accessible. Some research has shown that specific antecedence traits, such as affinity towards computer games, confidence with game playing, and comfort with game activities may influence outcomes [101]. In this research some profiling information was collected so that test scores could be compared with general traits such as age, gender, and education, and tested for significant variations and influence through factor analysis.

## 4.2 Design Process

The design of this teaching environment (Figure 8) was informed by research into the design of educational games and the creation of flow states. Designing a game with a theme and narrative not only gives it real-world relevance [102], helping the player to relate mistakes and corrections to past experiences, but it also enables the player to "hope" [103] which is an important aspect of motivation, driving the player to the next challenge regardless of how difficult they find the task. Han et al. [103] suggest that emotion is a key motivator in games based on forward-moving narratives and may account for the continued use of applications (in this case games) with low satisfaction rates, as is "the extent of user involvement" which is also positively associated with "hope", and in this design is driven by game feedback. The content of the challenges arises from cognitive linguistics theory [93], [94], however, the design of the challenges is informed by the motivation intensity model [104] in that it seeks to avoid cognitive overload and a disproportionate task/reward balance. i.e., the player should not see success as unlikely and therefore does not want to expend effort on it. This is a counterpoint to the function of "hope" and informs the balance in the design of the challenges. The design attempts to encourage flow [105] (a state of cognitive absorption) by creating clear goals (the islands and challenges are all visible), immediate feedback (all actions receive feedback) and a sense of control (no time limit and no movement restrictions) for the player. The design of the game attempts to include [50]:

- Cognitive consequence: focused on what is learned by playing the game
- Media comparison: was the game better than other teaching methods at delivering learning outcomes
- Added value: focused on features of the game and their effect on learning

This research attempts to measure what has been learned through player demonstration. The player must correctly enact the solution demonstrating their understanding of the solution and their ability to reproduce the solution.

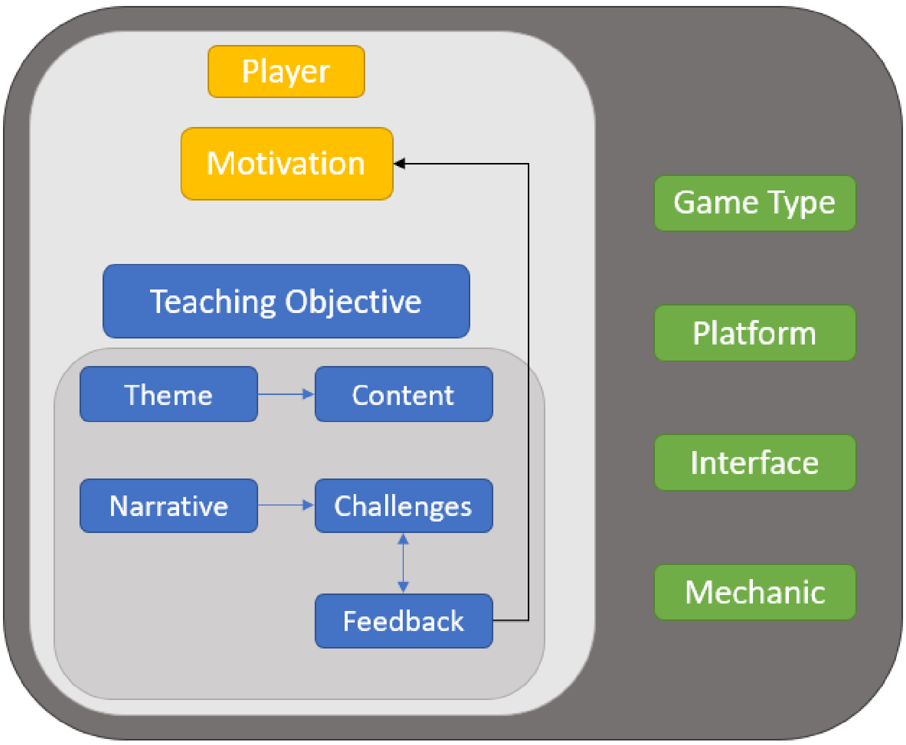


Figure 8. Design Model

All game design processes begin with a definition of the intended player or the target audience. In designing Serious Games (SG) for education this is driven by the teaching objective. In this case, the target audience is undergraduate and postgraduate participants who attend or attended an English-speaking university and speak English as a second/foreign language. Under these requirements, this audience was inevitably biased towards younger participants in tertiary education with an expectation of a high degree of English fluency. There was no first language criterion evidenced by Figure 69. Erhel et al [50] in their paper on instructions in educational computer games outline three steps to meaningful learning:

1. Selecting relevant incoming information
2. Organising information into coherent cognitive representations
3. Integrating the cognitive representations into prior knowledge

They suggest that the cognitive demands of an educational game and the instructions given affect how these are achieved and suggest that extraneous cognitive processing is caused by poor instructional design.

This research design avoids extraneous text inside the game wherever possible. While the initial effect of this is to reduce the potential for misunderstanding instructions, given the varied number of participants' cultural backgrounds, the primary intention is to encourage the participants to be guided by the game design and narrative, with reference to cognitive learning theory [21], [18], [35]. In doing so cognitive load is reduced.

**Design notes**: avoid extraneous text, let the game design guide [21], [18], [35] [38], [39], [41], [42]

The level of familiarity with technology was also assumed to be fairly high compared to the general population. Participation in the remote version of the research may have been a self-selecting criterion as to participate the participant was required to download and install the game onto their PC.

## 4.3 Challenge Descriptions

To help contextualise the design elements described in later paragraphs the challenges themselves are described below. To recap (Figure 4) the senses (meanings) of "over" are "over" as in above, more than, cover, other side, fallen (reflexive), repetition, focus, complete, beyond, transfer, preference, control and time (temporal).

The proto-sense challenge required the player to select items which were capable of hovering over the target boxes. In the PC environment, the player could stand in the centre of the island and using the mouse cursor, pick up and drop each item onto a box. In the VR environment, the player had to walk to the table shown in Figure 9 on the right, pick up an item and walk to one of the boxes in the foreground on the left, this made the VR process slower when compared to the PC environment.


Figure 9. Challenge Proto Sense

The excess sense challenge required players to remove the excess coconuts from the boxes as shown in Figure 10. With the PC environment, the player could stand in the centre of the island and simply click with the cursor on each of the excess coconuts to remove them. With the VR environment, the player needed to walk to each box physically grab the excess coconut and remove it.

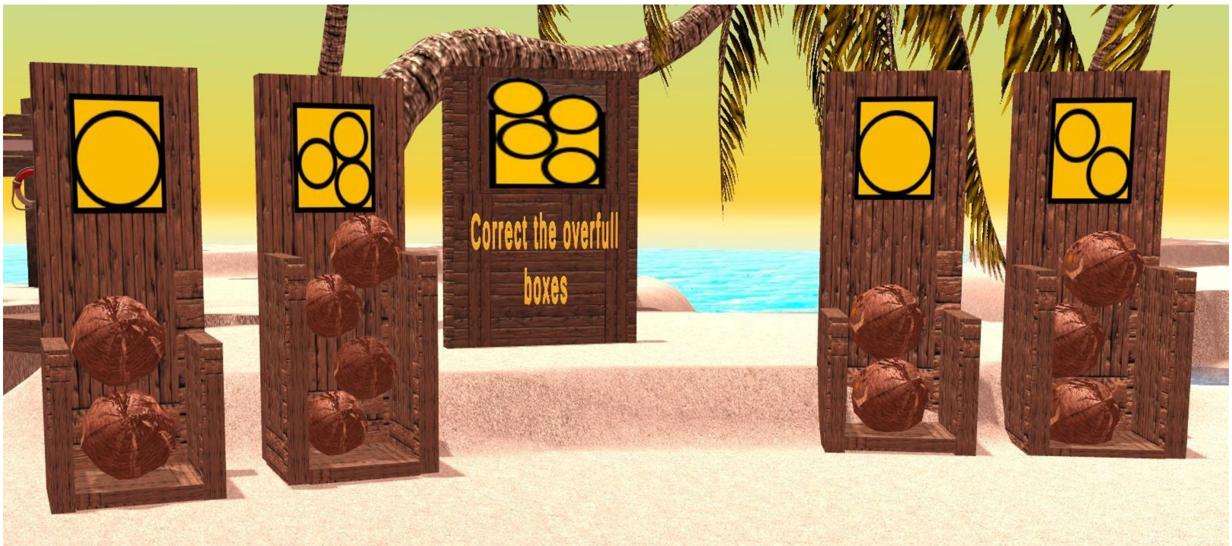


Figure 10. Challenge Excess Sense

The cover sense challenge required the player to take items from the table shown in Figure 11 on the left and use them to cover holes in the boxes on the right. Again, the PC player could do this from a standing position whereas the VR player needed to walk over to the table pick up a crab and place it over the holes in the boxes.


Figure 11. Challenge Cover Sense

The other side sense challenge (Figure 12), had a slightly different mechanic for the PC environment in that when the player selected an item with the cursor, instead of the item moving towards the player so that it was held in an imaginary hand, the item moved to a central position over the wall. When the player moved the cursor over one of the boxes on the right of the wall the item then moved from the central position over the wall to the box. This design was created so that the player had a very clear sense of moving an item over to the other side of a landmark (chapter 2. 5). The VR player had to walk to the table and carry the item around the wall to the boxes.


Figure 12. Challenge Other Side Sense

The reflexive challenge (Figure 13), required the player to select the fish on the table which had fallen over and place them on one of the boxes. Again, for the PC player, it was possible to complete this task from a central position whereas the VR player needed to walk to the table pick up the correct item and place it on a box.


Figure 13. Challenge Reflexive Sense

The challenge to repeat a pattern (Figure 14), required the player to place the correct kind of bird in order on the boxes. Due to the size, some boxes in the "ordering" challenge PC players were required to move around this island to complete the task. VR players needed to walk to the table on the right-hand side pick up a bird and then walk to the correct box on the left.


Figure 14. Challenge Repeat Sense

The focus challenge required the players to spot the difference in the fish on the table (Figure 15). To do this both the PC and VR players needed to move close to the table and focus on the fish. Once they had decided which fish were the odd ones, they could select them.


Figure 15. Challenge Focus Sense

The complete challenge (Figure 16) needed the crab to be moved through a cycle of boxes marked "start", one, 2, 3, and "finish". The PC player could complete this task by standing in the centre of the island and not moving whereas the VR player needed to go to each box and place the crab on the top of the box.


Figure 16. Challenge Complete Sense

The beyond challenge (Figure 17) was significantly different for the VR players. It required items to be taken from the table and throne over a wall. For the PC player, this process simply required them to click on the item and then click somewhere over the wall and the item would then fly in that direction. However, for the VR player, the action was to pick up an item and throw it exactly as they would in the real world.

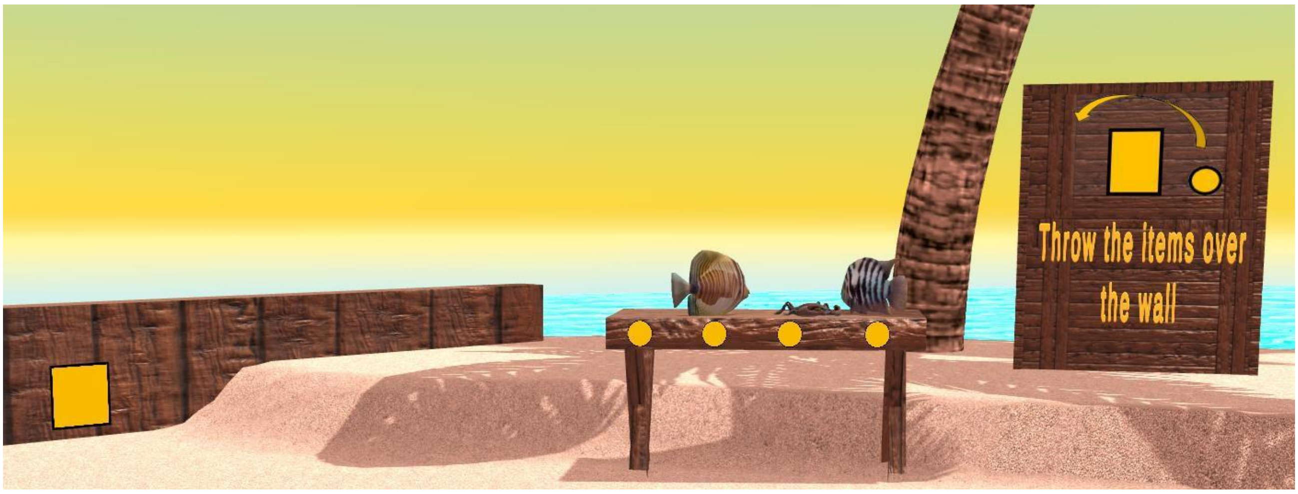


Figure 17. Challenge Beyond Sense

The transfer challenge (Figure 18) involved collecting items from a rock and transporting them across a bridge to a box. Again, this challenge could be completed by the PC player from the centre of the island.

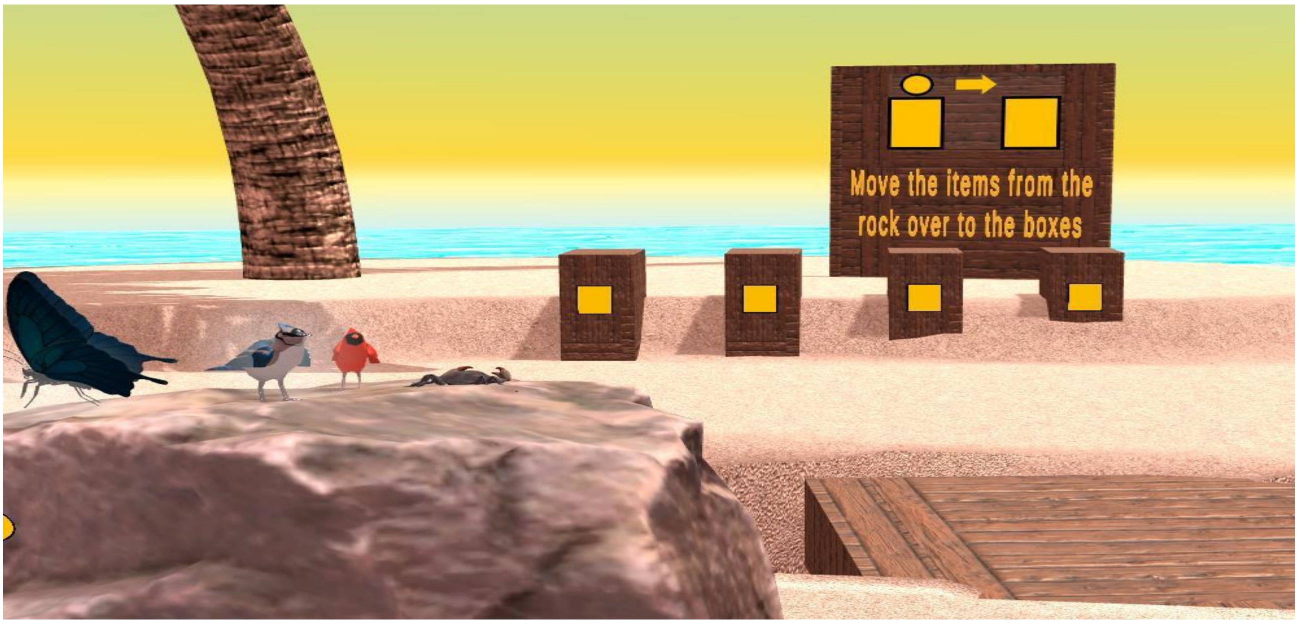


Figure 18. Challenge Transfer Sense

The preference sense challenge (Figure 19) required the player to select a food item other than coconut for the birds sitting on the rocks. When the correct item was selected the bird would hop from the rock onto the box and start eating or pecking at the food item. Again, PC players could complete this from the centre of the island without moving.

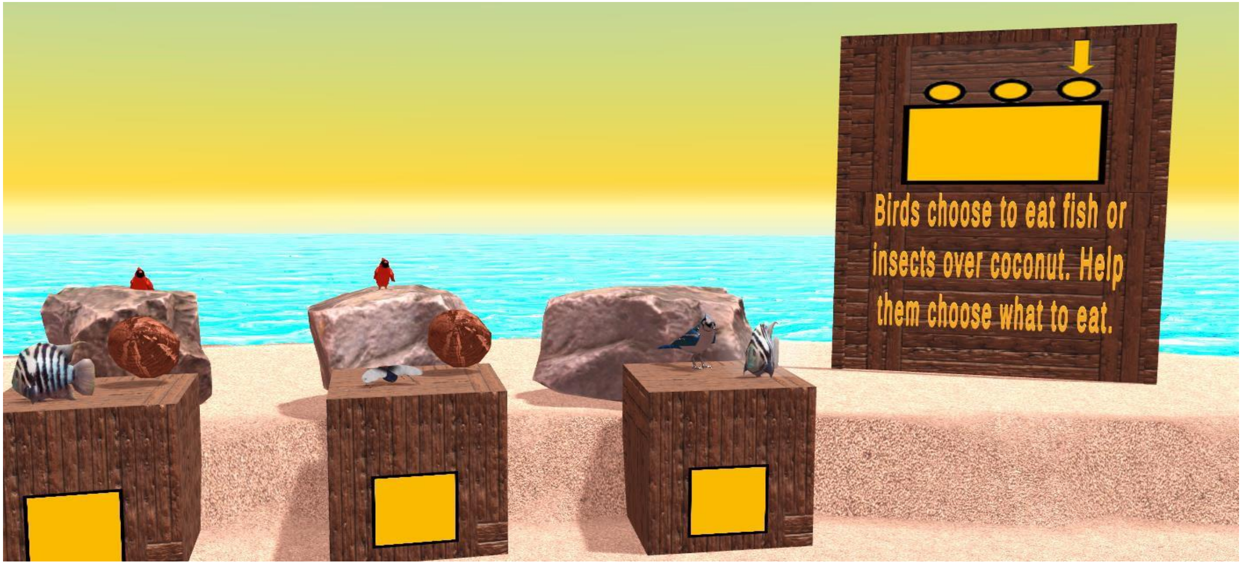


Figure 19. Challenge Preference Sense

The control sense challenge (Figure 20) required the PC player to click on birds which were flying around a tree. When they were clicked, the bird would stop flying and the PC player would be able to move their mouse cursor over a box to place them. The VR player needed to catch the birds in mid-air, and when one had been caught, the bird would cease to fly and remain still whilst they moved it over to the box.


Figure 20. Challenge Control Sense

The final challenge (Figure 21) required the player to understand that there was a difference between "during the day" and "during the night". All of the items on the table to the player's right could be placed in the chest at any time, however, they would only remain there if they were placed during the night. On this island, the day-night cycle was automatic and very quick so that the player had a sense of the day turning tonight and the night turning today.


Figure 21. Challenge Temporal Sense

## 4.4 Theme and Content

While as previously mentioned the content is deliberately minimalistic (section 2. 6) this research does in some ways adopt a contrary position to cognitive load theory [38], [39], [41], [42] because in the adaptive version it adds environmental activity to the game. However, it also has to ensure that the participant’s focus on the challenge is maintained. A desert island theme (Figure 22) was used as the game backdrop for simplicity. The structure of the platform is modular and designed so it can be transferred to multiple settings. Only visible proximal objects are legitimately related to the challenges, a feature which is intended to reduce distraction. The player only has access to one island at a time encouraging focus, as the player can only affect the objects close to them and can only attempt one challenge at a time. In the adaptive environments, some objects react to the player providing feedback however this is limited to proximal objects only. Environmental feedback is generalised not centred around any challenge and is also only active in adaptive environments. The challenges themselves are intended to be complex enough to maintain the participant's interest while avoiding actions unrelated to the challenges [102], [103], [104, p. 2].

**Design notes**: use theme to reduce complexity outside of the immediate challenge [50], [98]

Figure 22. Island Theme

The challenges which make up the content of the game are designed to allow the player to enact the sense (meaning) of the preposition "over" based on a cognitive linguistic model (2. 4). They are not intended to increase or decrease in difficulty as the participant progresses, but simply represent the concept being taught.

**Design notes**: content fidelity, only flow relevant challenges in the game [102], [103], [104, p. 2]

Aligning a game design with relevant learning theories is challenging. Figure 23 shows an attempt to bring together the game activity with the mechanics, dynamics, and aesthetics of the game design as well as grouping them with related theories.

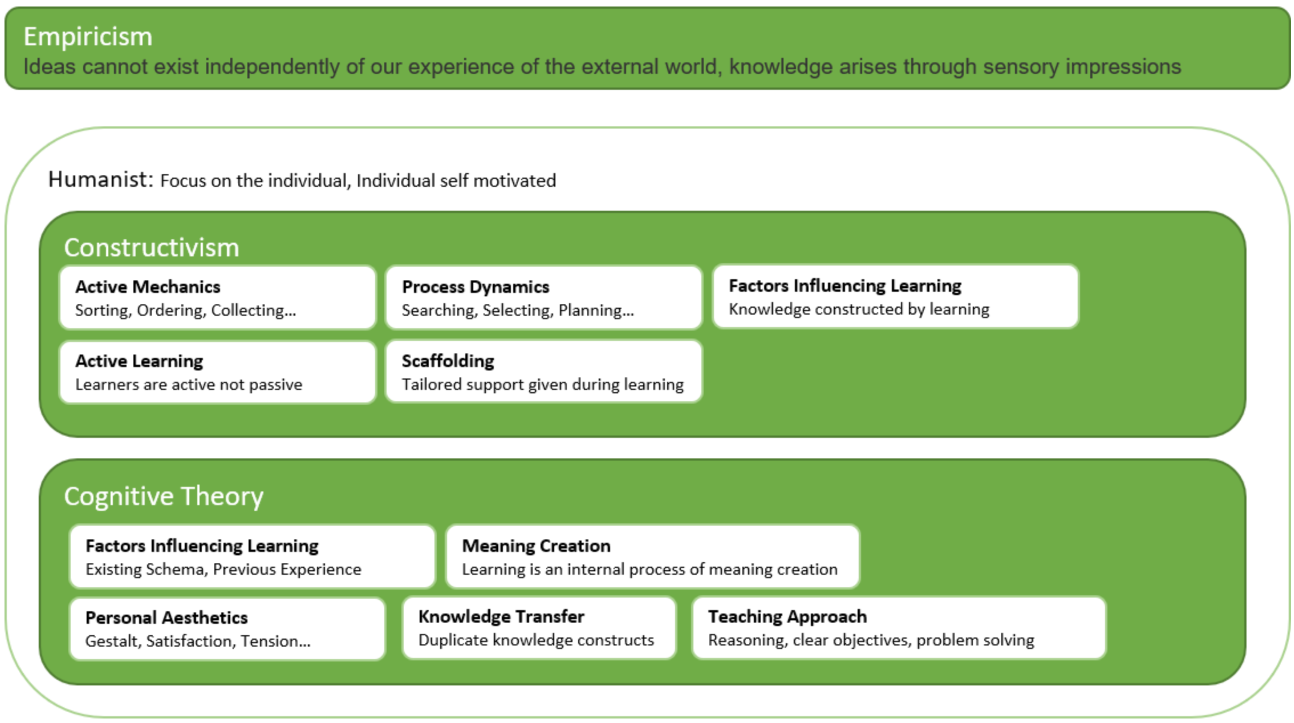


Figure 23. Design & Learning Theories

## 4.5 Game Narrative and Immersion

A game narrative is an essential component in the quest for immersion and describes the context which supports the goals, rules, and challenges of the game. In this game, the narrative is being stuck on a desert island surrounded by other small islands and having to complete challenges to move from one island to the next. The narrative helps the player to understand the intended flow of the game and appreciate the requirements for success, essentially acting as a shortcut to understanding through iconography. While the narrative supports immersion, an enhanced game experience does not necessarily result in improved learning efficiency. DeSmet et al [98] in their meta-analysis of the effectiveness of serious games and their attempt to design a game against cyberbullying suggest that more challenging games result in higher cognitive load and less fun for the player. They also suggest that the use of mechanics, aesthetics, and narrative to create simple challenges resulted in higher game effectiveness. In terms of this research, the design emphasises simplicity with a straightforward game narrative, individual-focused challenges and basic player interaction mechanics. These are especially important in this research environment as the player must move from novice to expert in the course of a single game session. In terms of narrative as a support structure for immersion, though the narrative is not inherent in the challenges, it is dependent on them [105], creating a forward movement and incorporating the educational content, as opposed to interrupting the game to deliver educational content [106, p. 662]. i.e., the game flows naturally from challenge to challenge without interrupting or disturbing the context. There are several research articles documenting the role of immersion in SLA including [107]–[110] and section 2. 7 which describes the positive effects of immersion on the participant although they describe real-world scenarios rather than virtual teaching environments. They describe the effect of teaching environments where the majority of language cues (scaffolding) are based on the second language (L2), i.e., the participants only have recourse to L2 references and must infer meaning from the teaching situation. These studies considered immersion from the point of view of being immersed in a language rather than immersed in a game, however, their findings may be directly transferable to game immersion in that the research environment does not contain any L1 scaffolding either, as with the study environments all meaning must be inferred. In the case of this game, to complete a challenge the player must understand the instructions and complete actions which match the meaning of "over" they refer to. Even L2 language as text is deliberately excluded from the research environment where possible. In the research environment "extra" content and "extra" narrative paths could be distracting, something educational games tend to avoid. The educational game objective is to have the player consciously process and reflect on the education challenges rather than controlling the game [105] i.e., the game provides the structure for teaching, wherein simplicity is favoured over complexity thereby reducing cognitive load.

For this research, a desert island scene represents the simplistic context of the game. The forward moving narrative is represented by the other visible islands which can always be seen but can only be reached by building a bridge to them, and each segment of the bridge requires the completion of a task (Figure 24).

Figure 24. Building Bridge Segments

There are four tasks on each island and each island represents a different sense of the preposition (Figure 25).

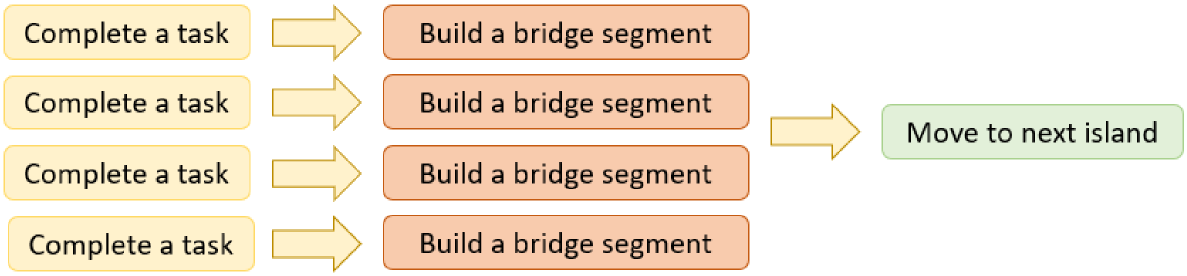


Figure 25. Flow

Once all twelve islands have been reached the game ends (Figure 26)

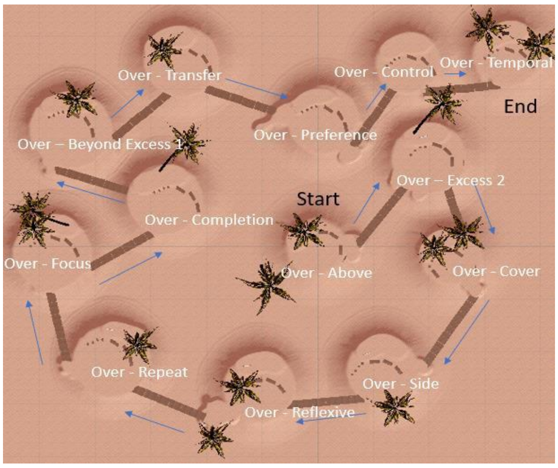


Figure 26. Flow Segments

## 4.6 Goals, Rules, & Challenges

As discussed in section 4. 5, the teaching environment requires the participant to master the rules (and nominally the mechanics) of the game in a single game session. Avoiding player frustration when doing this, [111] was a key goal in the design of the remote game (PC version) as it could have had an impact on the motivation to complete the game, and so both a tutorial to explain goals and mechanics, and a "pop-up" help screen, were included in the remote game design (The VR game participants had the advantage of the researcher present in the room to offer support). These aids on the remote game were optional to allow experienced gamers to infer what the rules and goals might be. However, initially, participants were encouraged to complete the tutorial by email. In keeping with the minimal text approach described in section 0 the description of the challenge is displayed on a board on each island, leaving the participant to infer their actions and the rules which might apply to the challenge. Essentially the rules are inherent, i.e., the participant can't walk on water to the next island, and the challenges are explicit and written on the signs (Figure 27).


Figure 27. Sign: Over (the other side)

The challenges remain the same regardless of the performance of the participant, there is no dynamic difficulty adjustment. The sense challenges are all fixed and so depending on the player's antecedents they may represent a range of difficulty [105], [112], [113] i.e., some senses of the preposition are more common, more obvious, or more explicit than others and the player with greater English competence might find the game easier to complete successfully. For this reason, each player completed an online profile form where they self-reported their English proficiency so that differences in test scores or environmental scores could be analysed. Each island challenge is an enactment of the conceptual sense of "over", and each challenge is different because the sense meaning is different. However, the game process is always the same and deliberately straightforward (Figure 28). The intention is that once the player has understood the sense and how to enact it, they master it quickly resulting in a feeling of achievement, they are then motivated to try the next challenge. There is no time limit to the game, the participant may try and fail as many times as they wish.


Figure 28. Challenge Process

Allowing unlimited attempts at challenges is not intended to create a mechanistic habit (stimulus and response) but rather to avoid frustration. The players soon learn that the behaviour on each island is unique even if the enaction appears to be the same. As described in section 4. 1 cognitive learning emphasises problem-based goal-directed behaviour (part of Relational Frame Theory (RFT) [114]). This is argued not to be habitual and is thought to be model-based, a self-driven strategic calculation focused on obtaining the optimal outcome [115]–[117]. In line with constructivism this behaviour is created through experience, is rule focused, and responds to environmental changes which are compatible with the research platform. This platform aims to provide an experience of the learning objective (the sense of a preposition), based on the rules associated with that preposition as it is enacted in the world through changes in the environment. Enaction is proximal i.e., based on or affected by how close the player is to the action, their proximity to the interaction objects, creating an embodied experience (chapters 2. 1,2. 7, 3. 3, 3. 4) as the participant is central to the actions and experiences the result of success or failure through environmental feedback. Goal oriented activity relies on the motivation resulting from achievement, and this is derived from developing competence. As discussed in the introduction, it is anticipated that L2 learners acquire confidence and esteem as their competence builds. In this context, the term competence is specific to psychology, not linguistics and is said to be created through learning goals, and performance goals intended to assess the level of that competence [99], [116]. In this research the learning goal is understanding how to correctly use the objects on the island i.e., demonstrating the correct form of the preposition. The performance goal is essentially to perform that understanding four times, the demonstration is the same each time (with different objects) reinforcing the idea that the participant has understood the sense of “over” in that particular sense and can by the end, easily demonstrate it, thereby building their confidence and esteem. For example, taking control “over” a flying bird may initially be confusing, however, once the player has grabbed a flying bird from the air (and as a result, it has stopped flapping its wings) they can repeat the action knowing they are enacting the correct sense.

There is a danger when designing a simple game that the participant becomes less engaged because there is less activity and depth to hold their attention [105], and so the game design pays particular attention to the antecedent states. This antecedent state i.e., the factor which immediately preceded the current flow state (the current place or challenge the participant is engaged with), is used to ensure the participant is motivated and rewarded [105] by providing anticipation of the next event. A forward-moving narrative implicit in the game itself allows the participant to see their next goal (the next island) so that they are motivated to reach it. They are then rewarded by the creation of the bridge to the next island. Rewards also come in the form of particle effect displays when a correct answer is demonstrated. Further particle displays occur when all of the challenges on an island have been completed. This emphasises to the player that they have demonstrated an understanding of the specific sense (both in the adaptive and static environments). The adaptive environments include additional, subtle loss aversion consequences such as the loss of light which follows an incorrect answer and incorrect items turning away from the player as well as other environmental changes such as an increase in wind and background noise.

## 4.7 Game Mechanics

Game mechanics describe the interaction a player has with the game, to progress [39]. Mechanics change with the game genre, for instance, this research uses casual game mechanics (sorting, matching, selecting etc.), for what is essentially a serious game. This signifies that the ontological representations of the semantic meanings of the preposition “over” are associated with the physical enaction of those meanings (Table 3). In linguistics, these are described as “senses” which in this research are presented to the participant as physical challenges on islands in the ocean.

Table 3. Senses, Mechanics and Definitions

| Senses | Mechanic | Definition |
|---|---|---|
| Transfer | Sorting | To arrange systematically in groups; according to type |
| Proto, Completion, Preference | Selecting | To carefully choose as being the most suitable |
| Excess I & II, Temporal, Reflexive, Control, On Side | Matching | To arrange according to a corresponding pattern, colour, or design; complimentary |
| Cover, Repetition | Ordering | To arrange (something) in a methodical way |
| Focus | Exploring | To examine or evaluate (an option or possibility) |

Each sense of “over” has its enaction independent of the item used for that enaction (Figure 29). It could be argued that the mechanics associated with the “sense” challenge on the island are grouped incorrectly as there is a certain amount of overlap between the actions. For example, arranging items (ordering) could be considered as selecting the items to be arranged. These groupings are therefore tested with factor analysis in section 7 to determine whether the groupings are consistent with the measurements taken inside the environment.

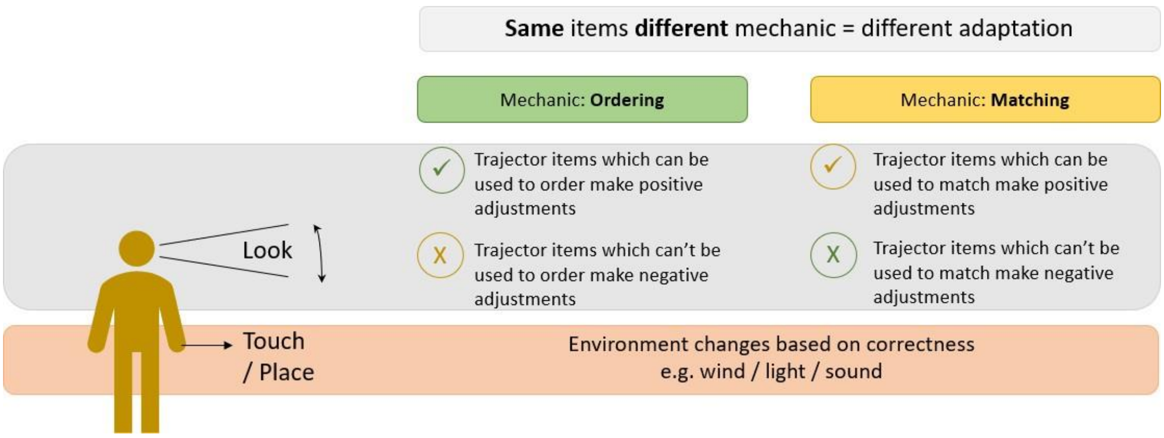


Figure 29. Actions and Mechanics

The vision was coded using raycasts coming from a central point and using the same degrees of focus that the human eye uses. Figure 30 shows the code used for both the PC and VR environments the main difference being that the code in the PC environment originated from the cursor position, whereas the code in the VR environment originated from the actual VR headset position inside the 3D environment. In the PC environment, the raycasts were only useful when triggering items to respond to what appeared to be attention i.e. When a cursor was over an item it was assumed that the item was focused on by the participant. As explained in the following descriptions of the challenges, in the PC environment it was possible for the participant to position themselves in such a way that they did not need to move but could use the cursor to complete the task. Originating the raycasts from the cursor position mitigated the lack of movement of the avatar in the PC environment.

```
//Setting up Vector3 angles for rays
fwd = transform.TransformDirection(Vector3.forward);
Vector3 fivedown = Quaternion.AngleAxis(-8f, transform.up) * fwd;
Vector3 fiveUp = Quaternion.AngleAxis(5f, transform.up) * fwd;
Vector3 fiveRight = Quaternion.AngleAxis(5f, transform.right) * fwd;
Vector3 fiveLeft = Quaternion.AngleAxis(-5f, transform.right) * fwd;
//Cast the ray names hits individually so any can be used
Physics.Raycast(transform.position, fiveLeft, out hit1, rayDistance);
Physics.Raycast(transform.position, fiveRight, out hit2, rayDistance);
Physics.Raycast(transform.position, fiveDown, out hit3, rayDistance);
Physics.Raycast(transform.position, fiveUp, out hit4, rayDistance);
Physics.Raycast(transform.position, fwd, out hit5, rayDistance);
//Draw the ray
Debug.DrawRay(transform.position, fiveLeft * hit1.distance, Color.black);
Debug.DrawRay(transform.position, fiveRight * hit2.distance, Color.yellow);
Debug.DrawRay(transform.position, fiveUp * hit3.distance, Color.black);
Debug.DrawRay(transform.position, fwd * hit4.distance, Color.yellow);
Debug.DrawRay(transform.position, fiveDown * hit5.distance, Color.black);
//use the array of hits to change the env
HitHelper(hit1);
HitHelper(hit2);
HitHelper(hit3);
HitHelper(hit4);
HitHelper(hit5);
```

Figure 30. C# Code for Vision

In the adaptive versions of the game, when an item which could be interacted with was hit by a raycast it would react based on whether it was a correct selection for the challenge being completed (Figure 31). Essentially items would turn towards the participant if they were correct and away from the participant if they were incorrect for the current challenge, however, if the item had been picked up it would cease to react. Items would also be highlighted with a white light if they were correct and a red light if they were not correct. The selection of an incorrect item would then trigger environmental changes such as increased wind speed noise and the initiation of a day-night cycle essentially turning day to dusk.

To collect statistics from the PC environment where the participants used a mouse instead of their head and hands, the definition of look, touch and place was defined as:

- Look, when the participant placed the mouse over an object.
- Touch when a participant pressed the right mouse button while over the object.
- Place, when the participant released the right mouse button after previously having held it down over an object.

```
public void AttractActionLook(int atr)
{
    //if holding something don't record look stats
    if (!pickPlace.mouseDn)
    {
        //stats - send look event name every second instead of every frame
        stats.AddStat(hCAgent.sense, "look", gameObject.name, atr);
    }
    //LOOK OBJECT REACTION
    if (atr == 1 && look && !place) //correct look
    {
        hiLight.enabled = true;
        // Determine which direction to rotate towards
        Vector3 targetDirection = player.transform.position - transform.position;
        // The step size is equal to speed times frame time.
        float singleStep = speed * Time.deltaTime;
        // Rotate the forward vector towards the target direction by one step
        Vector3 newDirection = Vector3.RotateTowards(transform.forward, targetDirection, singleStep, 0.0f);
        // Calculate a rotation a step closer to the target and apply rotation to this object
        transform.rotation = Quaternion.LookRotation(newDirection);
    }
    if (atr == -1 && look && !place) //incorrect look
    {
        Color ChangeCol = Color.red;
        hiLight.color = ChangeCol;
        hiLight.enabled = true;
        // Determine which direction to rotate towards
        Vector3 targetDirection = player.transform.position - transform.position;
        // The step size is equal to speed times frame time.
        float singleStep = speed * Time.deltaTime;
        // Rotate the forward vector towards the target direction by one step
        Vector3 newDirection = Vector3.RotateTowards(transform.forward, -targetDirection, singleStep, 0.0f);
        //Calculate a rotation a step closer to the target and apply rotation to this object
        transform.rotation = Quaternion.LookRotation(newDirection);
    }
}
```

Figure 31. C# Code for Attention Reaction

## 4.8 Motivation & Feedback

The goal of this teaching environment was supported by increasing intrinsic motivation and mitigating the impact of failure. The research takes advantage of the “Psychosocial Moratorium Principle” as described by Gee [118], where reducing the negative consequences associated with failure has the effect that the participant is more likely to take risks in their actions. In effect, there is no cost for failure in the environment. Progress is gated, which means the participant is essentially stuck until they solve the challenge, but they are not punished i.e., they do not perceive any loss. While loss aversion can be a powerful motivator, the tension it creates can be seen as an incentive to avoid potential loss (when the balance of the outcomes is negative) and encourage the participant to be risk averse [119].

**Design notes**: no punishment for any action [119]

However, players do need indicators showing they have taken an action which does or does not solve the challenge. This is provided through explicit feedback systems in both adaptive and static environments.

When viewed through the lens of linguistics it is worth noting that the feedback system does not recast (show the player the incorrect actions), it resets them by returning the incorrectly chosen item to its original position. On the one hand, this is an explicit indication that the answer was incorrect, on the other, there is no scaffolding to help the L2 participant identify the problem other than the limited number of options available on the islands and the implicit nature of the items, for example, a bird can hover over a box, but a turtle cannot. Only when the correct answer is found can the player infer the reasons and meaning missing in the first incorrect answer. Because there is a limited number of items on each island the participant is likely to find a correct answer eventually by simply being persistent. This trial and error process is helped by the effect of inhibition of return.

**Design notes**: limited options maintain forward motion [120]–[122]

Attention can be primed or inhibited based on previous events. Humans have a specific behaviour which may be linked to efficiency called inhibition of return (IOR) [120]–[122]. This is manifest when a person is slower to move their attention back to an object they have recently focused on. This is suspected to be a form of prioritisation i.e., old objects are less important than new objects, and are based on the object rather than the location. However, IOR can also be seen in the motor responses of a person reaching for an object which will be slower to return to the same place. Here the difference is that with action (relevant to this research based on enaction) the inhibition is based on the location of the object as opposed to with vision and attention where IOR is based on the object. These are not binary effects; they are small changes in probability and are influenced by context. Inhibition of return is controlled by the motor cortex and so is considered habituation rather than conscious decision or policy [29, p. 61], [120], [123, p. 290]. While it is intended that IOR encourages forward movement in the environment it is also possible that when the adaptive environment uses diegetic stimuli to create feedback, it may distract attention away from the task. The resulting IOR may then reduce participants' performance in comparison to the PC static environment [122, p. 32].

Continuing to view the environment through the lens of linguistics, the design for the experimental condition (adaptive environment) was based on an adaptation of the neo-Vygotskian metaphor of scaffolding i.e., supportive conditions helping the participant navigate the challenges and attempt to demonstrate (enact) the wide range of meanings of the English preposition "Over" (Table 4).

Table 4. Scaffolding Map

| **Scaffold Action** | **Approach** | **Example** |
|---|---|---|
| Creating Interest | Challenges presented in the form of a game | 12 desert islands each with its own challenge (fig. x) |

| | | |
|---|---|---|
| Simplifying | Each sense of the preposition is focused on separately | Each challenge requires a "pick & place" action only the context changes |
| Maintaining goal pursuit | The Game is designed with a forward-moving narrative | Each correct action builds a bridge to the next island |
| Marking Errors | Incorrect choices elicit feedback | Items & environment change |
| Controlling frustration | A method for skipping a challenge is provided | Selecting a lifebuoy will skip the island & challenge |
| Demonstrating Solution | The instruction for the challenge is accompanied by a diagram | Instructions are on a sign on each island accompanied by a diagram. Animated text mimics enaction |

Positive feedback through reward and encouragement helps participants recognise linguistic cues and internalise and automate skills. In the real-world positive feedback is a "negative feedback loop" i.e. the more a participant succeeds the less interaction (and therefore encouragement) they receive [124, p. 117]. This feedback loop is reversed in a VR game environment where positive feedback forms part of a motivational system which is cumulative, in that it represents building a bank of success which can be "cashed in" at some point in the future, for example, in the research game each success builds a step which eventually allows access to the next island.

When L2 participants attempt to learn English prepositions initially the error level will be high, and for the reasons outlined earlier, priming and recasting (the linguistics description of reformulating incorrect sentences and repeating them to the speaker) (section 2.7.1) may not offer sufficient cues to direct the participant towards the correct approach. High demands on the participant's memory and cognitive processing slows their transition from declarative knowledge to procedural knowledge [124] resulting in frustration and reduced motivation. For these reasons feedback, motivation, and participant engagement, specifically in the seemingly idiosyncratic world of English prepositions may be key to linguistic automation.

Feedback in VR is multifaceted as the participant can simultaneously be rewarded, penalised, gated (prevented from moving forward), and encouraged. Again, this is described in Cognitive Load Theory (CLT) and may represent our real-world experience which is simultaneously changing and influencing our perceptions. i.e., it is not linear and not procedural and forms part of an integrated motivational system [51]. The modality effect described in CLT is said to occur when participants need to process two or more separate sources of information which are related but do not have meaning unless they are integrated. If these sources of information are all based on one form of delivery for example sound, then the resulting sensory input for the participant can exceed their working memory and cognitive overload is the result, (a noisy room for example) [ibid]. The use of multiple modes to deliver feedback and the alignment with Filter Theory [29] are discussed in section 4. 9.

## 4.9 Situational Awareness & Attention

The following specifically relates to adaptive environments.

Much of the feedback in the adaptive environment relies on situational awareness (SA) i.e., from the perception of changes in the environment in which the participant is immersed, although the feedback is not exclusively environmental. Psychologists describe SA as functioning on three levels; 1) perceptual processing of the environment, which is manifest in the adaptive version of the environments in the changes in wind, light and sound; 2) integrating this information in a meaningful way; 3) goal relevant activation [29]. Using situational awareness directly to attempt to drive behaviour increases the cognitive load on the participant (Chapters 2. 6, 4. 1). However, the situational changes in this environment are not directly related to the participants' goal, i.e., they do not need to refer to them directly. There is an argument that the participant’s attention may not be drawn by their SA and these changes may be filtered out. In psychology attention is broadly debated as 1) capacity theory suggesting a spotlight which allows focus without ignoring the surrounding inputs, 2) filter theory based on the idea that attention is the result of the selection of relevant information, 3) noticing theory where attention is limited, selective and controlled by the individual [125, p. 42]. This research relies on capacity theory as it supports the idea that subjective awareness is not necessary for learning. i.e., changes in the larger world may be detected and processed without the need for the participant to focus on them [ibid]. The modality effect [51, p. 129] may also reduce cognitive load as the changes intended for SA are sound and sight based while at the same time spatially everywhere i.e., they are not proximal and cannot be interacted with. For example, while driving a car, events on the street represent a specific mode, proximal awareness, and events in the car (feedback from the steering, engine noise, warning lights) represent another, driver attention to the road might be considered another, all given varying degrees of attention. In this example, nothing is excluded but attention is “focused” on the road. Short-term memory is key to detecting changes which may require attention and so time is a factor in SA, dynamically conceptualising into meaning whatever requires action [125, p. 39].

The research environment design attempts to take advantage of the dynamic nature of conceptualisation by recognising that conceptualisation occurs over time, especially in learning a language. When understanding the meaning of a written sentence we can suspend our analysis of it until enough information has been read. Similarly, this environment attempts to provide information (environmental responses) which becomes significant when the task is complete. That is, the consequence of the task is understood and the meaning of the environmental response is clear [17, p. 167], [126, p. 84]. Arguably, where the feedback corresponds with the participant's attention, this could be considered due less to SA and more to focus.

While the PC and the VR platforms deal with attention in very different ways through their user interface (UI) (Section 4. 10) the following is a summary of the current literature concerning vision and attention. As this is an extensive subject only elements relevant to the research are included.

**First Order Vision** does not require conscious brain direction and includes rudimentary processes such as contrast, spatial differences, and fundamental edge detection. These are processed by the eye and brain without any conscious intervention and are the principles by which a visual scene is constructed [29]. For this research any significant difference between the first-order vision in the world and vision in the PC or VR environment is unlikely. The eye has a specific centre of detection which is five degrees on either side of the centre of the gaze. This is the area with the greatest concentration of photoreceptors in the retina and outside of this five-degree area, there is a significant drop in receptor cells resulting in a reduced detection ability. This area of detection changes significantly in low-lighting conditions where the perception range increases due to a difference in the distribution of Rod cells which are responsible for vision in low light [29]. This "Centre of detection" is replicated in the VR environment by using raycasts (analogous to lasers directed at angles from the eye position of the participant), which have the same five-degree angle, extended to ten-degrees in low light. In the PC environment, raycasts are accessed through the mouse cursor moving over an item.

**Higher Function Vision** such as colour vision may be related to consciousness, i.e., the brain does not construct colour vision without being aware of it. Similarly, attention to a scene already created in first-order vision is thought to be related to consciousness, as is the process of selection from that scene. What attracts a person's attention in the environment, whether it is the objects and actions in the environment or a perceptual set i.e., existing preconceived ideas and knowledge, or foreshadowing, is still debated among psychologists [127]. Attention may be drawn to an object because of a "bottom-up" environmental stimuli or salience map, or existing conscious knowledge of the objects in that environment.

**Research Environmental Features Based on Vision and Attention.** While attention is important for the completion of tasks, focusing on objects based on their properties as described in the Gestalt theory of visual perception [30], [128], [129] will not help participants understand the meaning of prepositions which are syntactically idiosyncratic or semantically polysemic. Further, it may be the case that the natural grouping of objects is a cause of misleading structural priming, as described in section (2.7.1 )[61, p. 54]. For example, just because a butterfly was the correct answer on one island does not mean it will be correct on the next. It may well be correct, but to avoid encouraging incorrect groupings of objects the environment uses the same objects in different tasks, each task requiring participants to create or use their schema i.e., the participant must use “top-down” attentional selection. Conversely, the adaptive environments attempt to guide participants by making objects change their movement, rotation, brightness, and saturation, to attract attention through “bottom-up” stimulus-driven. Objects which have ‘faces’ are used to enhance their ability to capture attention. Irrelevant objects in the adaptive environment are turned to face away from the player discouraging attention and forming part of the scaffolding [130].

In summary, no single feature of vision or attention is relied upon, and the player's perception of the entire environment attempts to guide learning.

## 4.10 User Interface Design for PC and VR

User interaction with both PC and VR game platforms is deliberately simplistic to avoid cognitive load (Table 5). The limitations of the PC game in replicating reality are evident in the need to use the keyboard to replicate head movement, a hand movement on the mouse to replicate general arm movements, and the finger on the mouse button to replicate grabbing an item (Figure 32). By contrast, the interaction within the VR environment has much more fidelity to real life (Figure 33). Though inevitably the participant will be aware of wearing the Oculus, their head and hand movements respond comparably with real-world movements. Even the grabbing motion using the handsets is essentially the same though admittedly without tactile feedback.

Table 5. User Interaction

| User Game Interaction | Mediator PC | Mediator VR |
|---|---|---|
| **Look** | Arrow Keys | Headset RayCast |
| **Touch** | Mouse Over Item | Handset Grip |
| **Grab / Place** | Mouse Button Down | Handset Release |


Figure 32. PC Game UI

Figure 33. VR Game UI

The main interactions are: “look” which is the main contribution a participant has to vision, in that they can choose what they look at and these choices are recorded, “touch and place” hand movements and haptics which indicates selection when an item is touched and choice when an item is picked up (Figure 34).

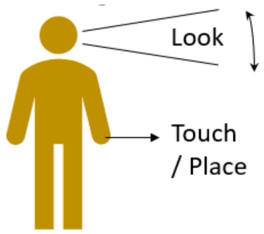


Figure 34. Environment Participant Components

When considering user interface design the change from PC to VR is extreme. Not only do the degrees of freedom (DOF) for movement increase dramatically (PC allows 2 DOF, VR allows 6 DOF) but the point of view (POV) from a flat screen to a freely moving headset is vastly different. Tapping a key several times to "look over your shoulder" bears no comparison with simply "looking over your shoulder". Haptics is essentially non-existent in the PC game, whereas the ability for a participant to see their own hands, grip objects, and naturally carry them is a de facto part of VR. The fluidity of movement and the fidelity of action in VR is demonstrably closer to real life. Haptics link the participant in VR to spatial and motor skill development and support embodied action [46], [68], [131]. This is important to the research as it seems clear that the "same visuomotor processes mediate both performing a given action and interpreting the action in others" [120]. i.e., cognitive embodied action constructs meaning (section 2.3). To maintain as much fidelity as possible with real life the user interface for the research restricts itself where possible to actions replicable in the real world. i.e., a participant must pick up an item, they cannot raycast to it from a distance. However, because of the variation in the precision of placement of items in the virtual world some license is used to "snap" an object to its correct position. This is done to support the visualisation of the final correct answer (see section 2.3 & Table 4).

## 4.11 Summary: Design of the Framework

This section considers the construction of a set of rules (a framework) for adjusting an environment. The absence of these rules will constitute the absence of an adaptive environment and will provide one of the control measures used in experimentation. It considers what can reasonably be changed, why those changes are relevant and how they might impact the participant. It reflects upon changes in the subject matter as well as the subsequent generalisability of the framework. Key considerations in the design are the adherence to a cognitive linguistic view, task representational fidelity, and the adoption of the scaffolding approach described in section 4. 8.

## 4.12 Design of the Framework

The framework is based on changes to selected elements of the game design. The changes applied are intended to be measurable and generalisable for future designs and employed depending on their effect on learning outcomes. The measurable elements are (Figure 35 ):

- The challenges. Each challenge represents the concept to be learnt and an independent variable.
- Environmental feedback. A player's correct or incorrect actions result in changes in the environment and the use of these changes i.e., an adaptive environment if they are used and a static environment if they are not used, represents an independent variable. Player actions are defined as “look”, “touch” and “place” (Figure 36).
- The mechanic (physical action taken by the player). Each challenge requires the player to use a specific mechanic which can be measured as an independent variable.

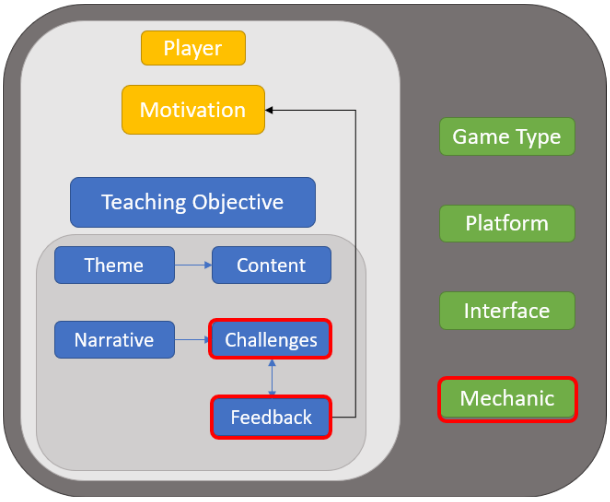


Figure 35. Design Framework

The dependent variable is the change in learning outcome scores.

Within the adaptive game attention (look) triggers changes in items and decision (touch) and action (place) trigger changes in the environment (Figure 36). What is triggered, the timing of triggers and the "correctness" (based on the current challenge) of the triggers, all provide data which can be compared to learning outcomes and the profiles of the participants.

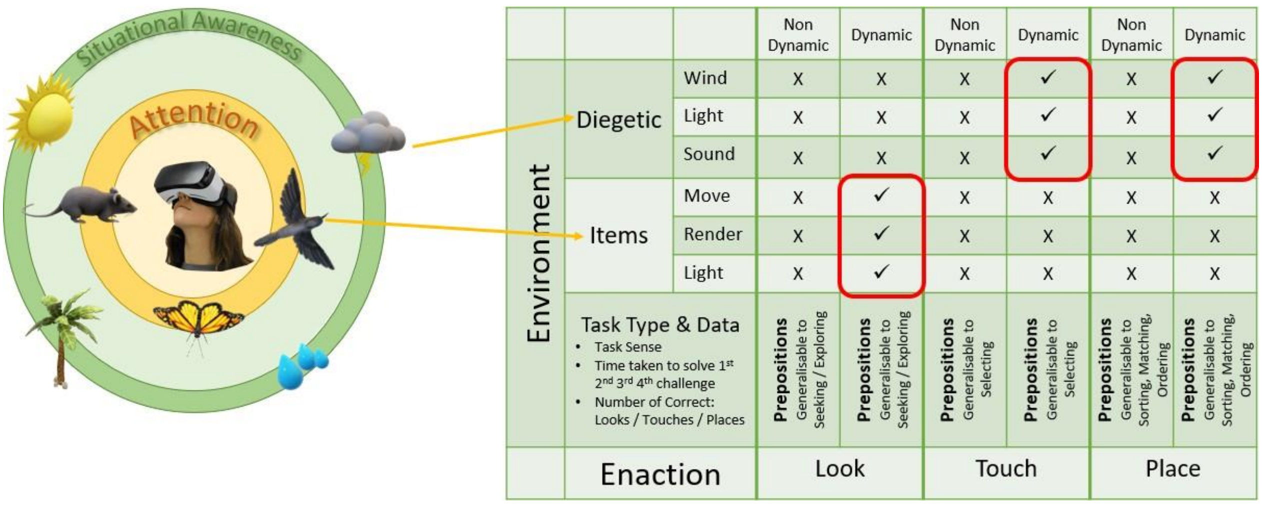


Figure 36. Adaptation Framework

The concept being taught through the challenge would traditionally be supported by a teacher responding to the participant's verbalisation and providing feedback which takes into account both the participant's level of knowledge and the new concept being taught. This is known as "scaffolding", bridging the gap in the zone of proximal development (ZPD) between current comprehension and new understanding [132], [133, p. 538], [134]. In this research and from a CL point of view, the items which gain the participants' attention are of key importance [17]. Importance is also attached to the participants' understanding of the unfolding scene and the consequences of any interaction they have with it (section 2. 5). Consequently, the game attempts to guide the participant's attention by adjusting the visual cues [135]–[137] (the game's version of scaffolding) between the trajector and the landmark, as well as provide feedback based on the interactions the participant has with the scene [115]. These adjustments are exclusive to the adaptive version of the game and are the game scaffolding as dictated by the framework. As far as possible, the game attempts to maintain realistic consequences using real-world physics and object interactions. However, adaptive changes based on the framework are used to gain participants' attention and are not based on real-world physics (Figure 36).

"Correctness", the extent to which the player is looking at; touching; placing; the correct item for the challenge, drives different feedback. Trajector items respond to attention (looking) by changing their orientation and brightness (Figure 37). The game responds to decisions i.e., touching or placing, by changing diegetics, for example, wind speed and noise may be considered negative feedback.

Figure 37. Example Action: Incorrect items turn away.

Using this design framework, the scene is constructed with tasks which link to the adaptation framework (Figure 38 ).

| Sense | Sentence | Primary Mechanic |
|---|---|---|
| Proto | "The moon was over the sea" | Selecting |
| Excess I | "The coconut was thrown over the rock" | Matching |
| Excess II | "Any number over 2 will tip the scales" | Matching |
| Cover | "The fish was over the corner of the box" | Ordering |
| Repetition | "The pattern appeared over and over again" | Ordering |
| Transfer | "Move the snail over to the box" | Sorting |
| Preference | "Fish choose fish friends over any other creature" | Selecting |
| Temporal | "Creatures can only be placed in the chest overnight" | Matching |
| Focus | "The bird looked over its meal" | Exploring |
| Reflexive | "The tree had fallen over" | Matching |
| Control | "The wind has control over the leaves" | Matching |
| Completion | "The task is over when the crab is on the box" | Selecting |
| Other Side | "The items are over on the other side of the wall" | Matching |

| | | | Non Dynamic | Dynamic | Non Dynamic | Dynamic | Non Dynamic | Dynamic |
|---|---|---|---|---|---|---|---|---|
| Environment | Diegetic | Wind | X | X | X | ✓ | X | ✓ |
| | | Light | X | X | X | ✓ | X | ✓ |
| | | Sound | X | X | X | ✓ | X | ✓ |
| | Items | Move | X | ✓ | X | X | X | X |
| | | Render | X | ✓ | X | X | X | X |
| | | Light | X | ✓ | X | X | X | X |
| | Task Type & Data<br>• Task Sense<br>• Time taken to solve 1st 2nd 3rd 4th challenge<br>• Number of Correct: Looks / Touches / Places | | **Prepositions** Generalisable to Seeking / Exploring | **Prepositions** Generalisable to Seeking / Exploring | **Prepositions** Generalisable to Selecting | **Prepositions** Generalisable to Selecting | **Prepositions** Generalisable to Sorting, Matching, Ordering | **Prepositions** Generalisable to Sorting, Matching, Ordering |
| | Enaction | | Look | | Touch | | Place | |

Figure 38. Adaptation based on the mechanic.

The design is generalisable in that the diegetic and item adjustments can be reproduced for any challenge. Framework Evaluation: The theoretical basis for this research requires a facsimile of "real life". However, it could be argued that environments which adapt do not represent reality. While being aware of this apparent contradiction and the possibility of an "uncanny valley" effect (a disconnection between items which look realistic, but are slightly unreal) [138], [139], the research relies on the human ability to adapt to unfamiliar environments and to accept abstraction from reality as mentioned earlier [115, p. 218], [140].

## 4.13 Code for Algorithms

### Overview

The main processes of both the adaptive and static game are controlled by a script called GameManager. This script initializes the challenges and monitors the actions of the player during the game. At the beginning of each level in the adaptive game environment, the game manager assigns a "correctness" flag to each item the player might interact with. This flag determines the behaviour of the item and the environment. i.e., when the player interacts with the item in an adaptive environment the game manager knows if the item is correct for that level and how to change the environment and object behaviour.

The algorithm needs inputs to tell it what it is looking at and what it is touching. For this, the script uses raycasts (analogous to a laser beam sent from the position of the head) to simulate sight (Figure 39) and a function called "OnTriggerStay" which is analogous to a hand coming into contact with an object and then staying or holding that object (Figure 40, Figure 41).

The algorithm simply checks the inputs and acts accordingly as shown in the following pseudo-code (informal outline of programming language).

Sight: if the laser from the eyes hits an object

- if the object is correct for the level do one thing
- if it is not correct for the level do another thing

```
private void FixedUpdate()
    {
        //Setting up Vector3 angles for rays
        fwd = transform.TransformDirection(Vector3.forward);
        Vector3 fiveDown = Quaternion.AngleAxis(-8f, transform.up) * fwd;
        Vector3 fiveUp = Quaternion.AngleAxis(5f, transform.up) * fwd;
        Vector3 fiveRight = Quaternion.AngleAxis(5f, transform.right) * fwd;
        Vector3 fiveLeft = Quaternion.AngleAxis(-5f, transform.right) * fwd;
        //Cast the ray names hits individually so any can be used
        Physics.Raycast(transform.position, fiveLeft, out hit1, rayDistance);
        Physics.Raycast(transform.position, fiveRight, out hit2, rayDistance);
        Physics.Raycast(transform.position, fiveDown, out hit3, rayDistance);
        Physics.Raycast(transform.position, fiveUp, out hit4, rayDistance);
        Physics.Raycast(transform.position, fwd, out hit5, rayDistance);
        //use the array of hits to change the environment
        HitHelper(hit1);
        HitHelper(hit2);
        HitHelper(hit3);
        HitHelper(hit4);
        HitHelper(hit5);
    }
```

Figure 39. Input script for "looking"

Objects "notice" when they have been seen or touched and react based on their "correctness". In Figure 39 the variable "atr" represents a Boolean switch. When it is 1 (atr==1) the item should attempt to attract the attention of the player. The same process is used for touch. Although touching something incorrectly is one degree of error, picking that object up and placing it as if it were correct (ignoring the already adapting environment) is a greater degree of error and as a result, increases the intensity of environmental change. For example: at the end of the code in Figure 40, "hCAgent" (the game controller) calls a function called "Wind2". This is similar to saying to the player "you touched it, it's wrong so you got Wind1, now you're holding it, it's still wrong so you experience more intense "Wind2".

```
//enact attraction material, movement etc
    public void AttractActionLook(int atr)
    {
        //stats - send look event name
        stats.AddStat(hCAgent.sense, "look", gameObject.name, atr);
        //LOOK OBJECT REACTION
        if (atr == 1 && look && !place) //correct object for level
        {
            hiLight.enabled = true;
            // is correct object for level so change look at position
            // Determine which direction to rotate towards
            Vector3 targetDirection = hCAgent.mHead.transform.position - transform.position;
            // The step size is equal to speed times frame time.
            float singleStep = speed * Time.deltaTime;
            // Rotate the forward vector towards the target direction by one step
            Vector3 newDirection = Vector3.RotateTowards(transform.forward, targetDirection,
            singleStep, 0.0f);
            // Calculate a rotation a step closer to the target & apply rotation to object
            transform.rotation = Quaternion.LookRotation(newDirection);
        }

        if (atr == -1 && look && !place) //incorrect object for level
        {
            Color ChangeCol = Color.red;
            hiLight.color = ChangeCol;
            hiLight.enabled = true;
            // Determine which direction to rotate towards (in this case away from player)
            Vector3 targetDirection = hCAgent.mHead.transform.position - transform.position;
            // The step size is equal to speed times frame time.
            float singleStep = speed * Time.deltaTime;
            // Rotate the forward vector towards the target direction by one step
            Vector3 newDirection = Vector3.RotateTowards(transform.forward, -
            targetDirection, singleStep, 0.0f);
            //Calculate a rotation a step away from the target & apply rotation to object
            transform.rotation = Quaternion.LookRotation(newDirection);
        }
    }
```

Figure 40. Input script for "touching"

```
void OnTriggerStay(Collider collider)
    {
        if (collider.GetComponent<TrajLMProperties>()
            || (hCAgent.sense == 5 && collider.tag != "Player"))
        {
            if (hCAgent.sense == 1 && !doOnce)
            {
                var rb = collider.GetComponent<Rigidbody>();
                if (collider.name == "PrepCardinal" || collider.name == "PrepBlueJay" ||
                collider.name == "PrepButterfly" || collider.name == "FlyHldr")
            {
                    rb.isKinematic = true;
                    rb.useGravity = false;
                    collider.transform.position = transform.position;
                    collider.GetComponent<Rigidbody>().constraints =
                     RigidbodyConstraints.FreezeAll;
                    collider.GetComponentInChildren<Animator>().SetBool("flying", true);
                    doOnce = true;
                    GameObject GO = transform.parent.gameObject;
                    hCAgent.Judge(collider, GO);
             }
             else
             {
                 if (collider.GetComponent<TrajLMProperties>().trajector)
                    {
                        hCAgent.Wind2();
                    }
             }
        }
```

Figure 41. Input script for "holding"

For video examples of these functions please go to:

- PC version adaptive “other side”: [https://youtu.be/1oaSdu7mpDE](https://youtu.be/1oaSdu7mpDE)
- PC version adaptive “above” : [https://youtu.be/0a6biKYhA2Q](https://youtu.be/0a6biKYhA2Q)
- PC version adaptive “control” : [https://youtu.be/M52w0vBZ7V4](https://youtu.be/M52w0vBZ7V4)

# 5 Research Usability Test

## 5.1 Rationale

Smooth interaction between the player and the game was an important part of the design as any failure of interaction or difficulties in understanding the interaction needed would create a new cognitive process. The user interface bridge is the space between the computer and the player and any extraneous interaction would become an agent acting between the player and the game and disrupt the cognitive learning process [141]. Usability tests were conducted with both the VR (before lockdown) and PC (during lockdown) games to obtain user feedback and ensure functionality. Specific areas of focus were:

- the data collection process
- the usability of the game itself
- to ensure that the overall procedures were fit for the purpose

At the time of this research, COVID-19 restrictions made VR participation difficult due to the proximity required. To comply with lockdown rules the VR pilot was conducted with the help of 6 adults, all members of the same household. The PC pilot was written as a standalone program and could be completed remotely.

## 5.2 PC and VR User Testing

VR User Test: Consent forms required by the university's ethical approval process were completed on paper and the profile and test questions were created within a game design platform known as Unity (Unity) (Figure 42). The game used the Oculus Rift played on an Omen laptop.

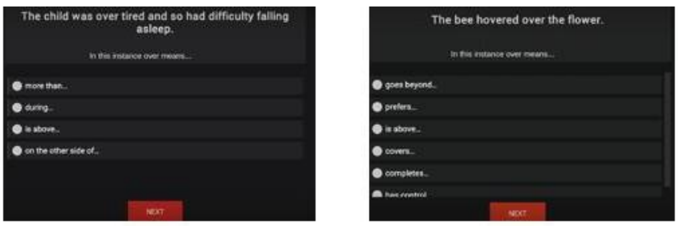


Figure 42. Unity-based test.

PC User Test: Here the consent forms, profile and test questions were Qualtrics-based (Figure 43). Participants used their PC to play the game.


Figure 43. Qualtrics test

Both pilots used the same version of the game. Instructions on the rules and objectives were given verbally with the VR platform and through an instruction pdf for the PC platform (Figure 44). Both sets of participants were asked in a guided discussion how they “found” the experience and what they found difficult and easy. Their comments are grouped and summarised in Table 7.

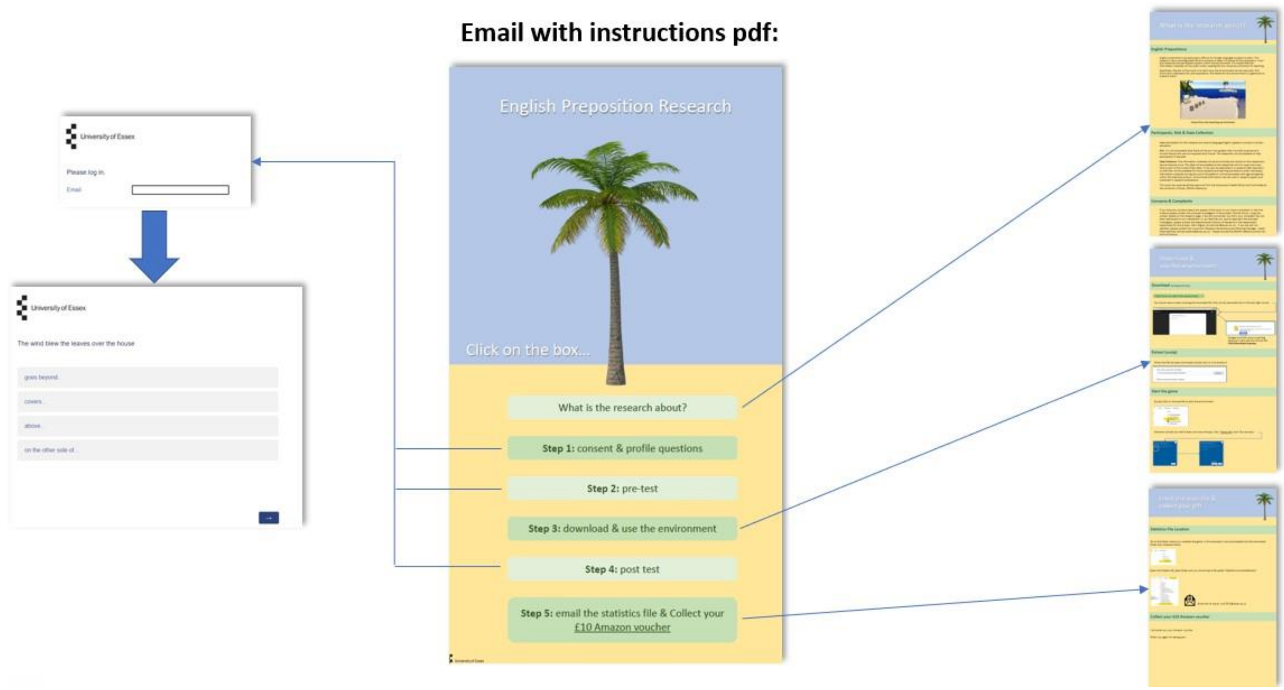


Figure 44. Pdf instructions for PC game

The participant profiles (Table 6) show an imbalance in the two pilots with 5 non-native speakers in the PC pilot. All VR participants completed the game and only two of the PC testers managed to complete the game, highlighting the difficulty of remote testing.

Table 6. Pilot Tester Profile

| Pilot | Male | Female | Native Speaker | Non-Native Speaker |
| --- | --- | --- | --- | --- |
| **VR Pilot** | 2 | 3 | 5 | 0 |
| **PC Pilot** | 2 | 4 | 1 | 5 |

Two participants completed the PC game without issue the remaining four did not finish due to a combination of the following issues:

Table 7. Qualitative comments

| **Issue** | **Comment** |
|---|---|
| Restrictions | locked in full screen |
| Restrictions | cursor is locked |
| Restrictions | Over the wall puzzle needs to have a larger space to walk around |
| GamePlay | task I didn’t understand what I was needed to do |
| GamePlay | completed throwing with 3 objects |
| GamePlay | I can’t pick up the coconut after dropping it |
| GamePlay | I got stuck in the 2nd game where I couldn't understand what it is that I have to do |
| Instructions | sentence and an image didn’t help at all |
| Instructions | video demo or a guided tutorial would help |
| Instructions | The game play could be better explained in the instructions page |
| Instructions | not clear what the user should do in some of the questions. |
| Function | carrying objects seems buggy |
| Function | placing on boxes can be tricky as there doesn’t seem to be a good snapping mechanic |
| Function | Left/right movement works fine, the S/W movement misbehaves sometimes |
| Function | It would be easier if movement between islands was also click n drag as well |
| Function | The moving buttons did not seem to respond well |
| Function | I found hard while playing the game is movement |
| Function | the objects just stayed on strange places and did not respond to new movement |
| Function | I was playing and the game freeze |
| Function | No PC only Mac |

A key concern with remote research is consistency of user experience. While all six testers had the same game environment their experience was very different. Only two completed the game without technical issues, the remaining four had varying degrees of stutter in movement and other video delays. While the game included a tutorial and instructions screen only one tester (both a native speaker and a computer gamer) understood their objective and carried out the tasks as needed. VR game completion was guided whereas the PC version required all cues to be more explicit, mechanisms for skipping the island to avoid frustration, improvements in the code to ensure more basic computers could cope with the game and an allowance for alternative keyboard configurations.

**Changes:** No changes were made to the VR instructions. PC instructions were made more explicit (Figure 45), a tutorial scene was added to the game (Figure 46), the instruction sign images were changed in the game (Figure 47), alternative movement keys were made available (arrow keys and number pad), a "skip level" option was added (Figure 48), the bridges and islands were made larger (Figure 49), the method used to pick up items was changed from placing the on-screen hand on the item and holding the mouse button down, to a simple mouse cursor over the item and then hold the mouse button down. This meant that the participant did not need to move to the item to pick it up and the coding was changed to avoid coroutines which slowed the game down.


Figure 45. Changes to instructions.


Figure 46. Instructions leading to tutorial


Figure 47. Sign changes

Figure 48. Skip island

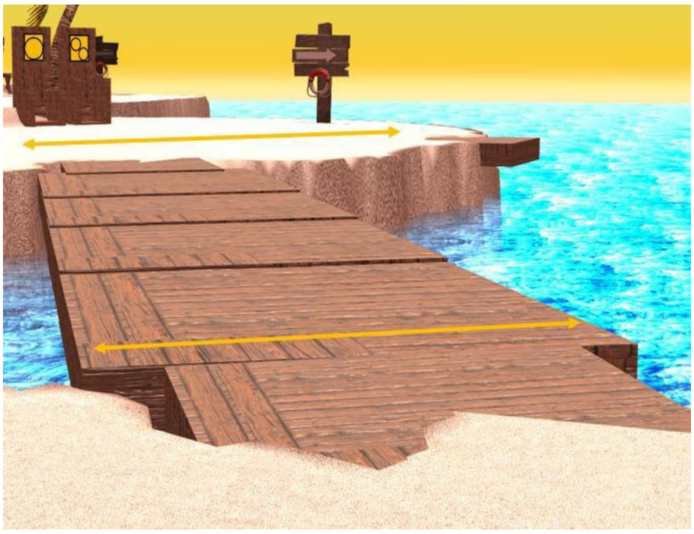

Figure 49. Bridges and islands expanded.

# 6 Research Methodology and Experiment Design

## 6.1 Introduction

The research objective was to investigate the question “how can environmental feedback be adapted to influence what is learnt? “(Section 1. 3) and was investigated through the application of the research questions which are explored using the challenges in the game (Table 1). The game with or without adaptive intervention represents the method of enquiry and provides context for the participants along with the data needed for measurement.

Table 1. Research Questions

| **Research Question** |
|---|
| **Research Question 1:** Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of ‘over’? |
| **Research Question 2:** Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile? |
| **Research Question 3:** Did performance vary by sense or mechanic? |
| **Research Question 4:** Did profile differences between participants factor in predicting performance in the VR or PC game? |

## 6.2 Hardware Configuration

The PC environment for the remote research did not require any special equipment. It was intended to be usable on the majority of medium-specification PCs:

- Minimum 8 GB of Ram
- Minimum 2 core 1.8 GHz CPU
- Windows 10 home or higher
- Dedicated video card

The PC game was less than 150 Mb in size and was downloaded from a google drive by each participant as shown in 9. 4.

The VR version of the game was intended to be deployed on the Oculus Quest which uses an Android platform as opposed to the PC Windows platform. The Android platform process graphics in a different way to the PC platform, using ASTC texture compression, fixed rather than float types for UV sets and lower graphics tiers as default. These differences are part of a wider configuration designed to optimize Unity programs for the smaller hardware capabilities of android devices. As the game was not intended for distribution and so did not need to rely on a compressed build, the Oculus Rift link and Air Link were used to access the VR game. Oculus Rift link and Air Link are methods for connecting the Oculus quest to Unity running in the editor on the PC. This essentially means that the user of the Oculus sees the benefits of the higher quality graphics and enhanced speed provided by the PC while still using a VR environment and allowed the PC and VR games to be extremely similar in graphics quality and performance. The Rift link is a physical cable connecting the PC to the Quest (Figure 50).

Figure 50. Rift Link to Quest

The Air Link (beta version) uses a Wide Area Network (WAN) to link the Quest with the PC. Figure 51 shows the configuration of the Air Link VR experiment. The Oculus Air Link needs to be on the same Wi-Fi network as the PC running the game and this PC needs to be paired with the headset. Additionally, the Headset needs to be able to link with the mobile phone which has the registered Facebook account.

This link could not work with the university Wi-Fi as the bandwidth speed needed to avoid stutter in the quest is more than a consistent 1Gb. The cable (Oculus Rift Link) was used as a backup to be used if any elements of the WAN failed Figure 51.

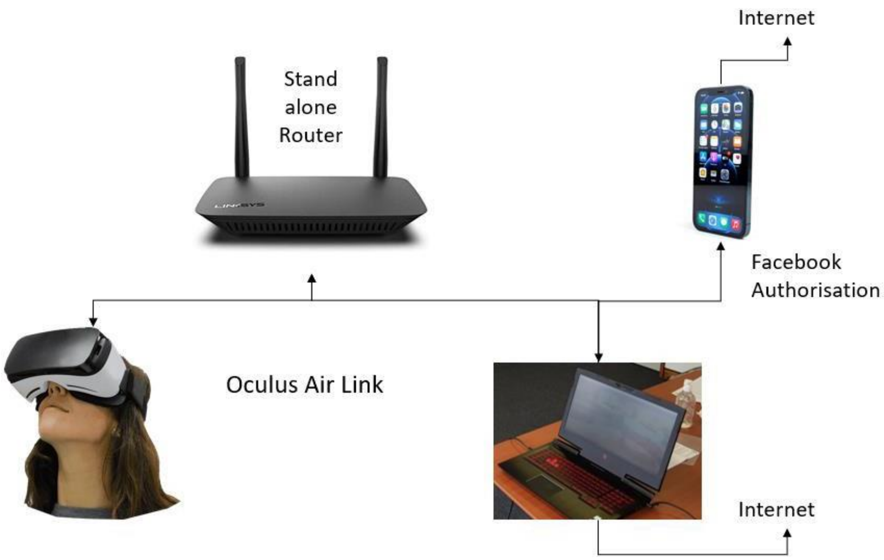


Figure 51. WAN Oculus Quest Setup

## 6.3 Experimental Conditions

The same game was created on PC and VR platforms both using the Static version as the control condition and the adaptive version as the experimental condition. The PC version was completed remotely by 40 participants and supported through email, and the VR version was completed on the university campus by 16 participants and was supported by the researcher (Figure 52, Figure 59).

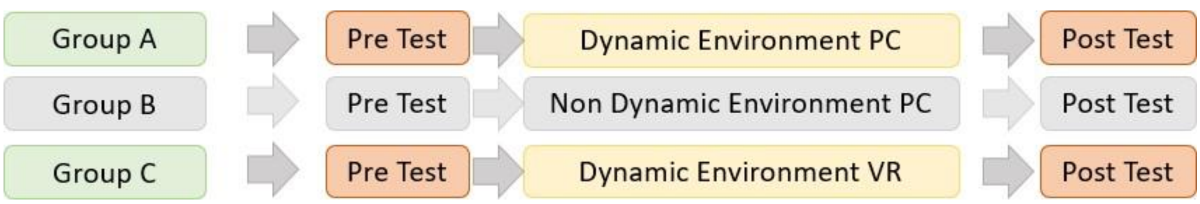


Figure 52. Experimental Groups

The experimental condition changes the environment in accordance with the framework (Table 10) suggested (Figure 36). These changes are intended to provide feedback to the participant in line with the social regulatory scale for feedback as described in [142, pp. 465–483]. This alignment can only be approximate as it is the game, rather than a human, teaching. The extent to which the regulatory scale matches the game feedback is outlined in Table 8. In the adaptive environment, the participant is prompted by the items they pay attention to, and environmental changes resulting from their actions which attempt to address their situational awareness (Figure 36). Whilst it is recognised that this scale was intended to describe the microgenesis in the Zone of Proximal Development [132], [143] supported by a human tutor rather than a computer game, in most cases, the scale is still relevant for "other derived" help [140, p. 471][142, p. 471].

Table 8. Regulatory Scale

| | **Regulatory scale – Implicit (strategic) to Explicit** [1] | **Game Version**<br><br>**Implemented** / **Not implemented** |
|---|---|---|
| 0 | Tutor asks the learner to read, find the errors, and correct them independently, before the tutorial | Challenge explicit in the game |
| 1 | Construction of a 'collaborative frame' prompted by the presence of the tutor as a potential dialogic partner | Correct items turn to face participant, incorrect items turn away |
| 2 | Prompted or focused reading of the sentence that contains the error by the learner or the tutor | Challenge explicit in the game |
| 3 | Tutor indicates that something may be wrong in a segment (e.g., sentence, clause, line) – 'Is there anything wrong in this sentence?' | Feedback from Environment |
| 4 | The tutor rejects unsuccessful attempts at recognizing the error | Items replaced in original positions |
| 5 | Tutor narrows down the location of the error (e.g., the tutor repeats or points to the specific segment which contains the error) | No new interventions from the environment, participant must study the situation |
| 6 | The tutor indicates the nature of the error but does not identify the error (e.g. 'There is something wrong with the tense marking here') | No new interventions from the environment, participant must study the situation |
| 7 | 7 Tutor identifies the error ('You can't use an auxiliary here') | The participant must infer from the items and their actions |
| 8 | The tutor rejects the learner's unsuccessful attempts at correcting the error | Items replaced in original positions |
| 9 | The tutor provides clues to help the learner arrive at the correct form (e.g. 'It is not past but something that is still going on') | The participant can try different items until they find the correct one and infer the correct answer |
| 10 | The tutor provides the correct form | The participant can try different items until they<br>find the correct one and infer the correct answer |
| 11 | The tutor provides some explanation for use of the correct form | The participant must infer from their actions why the answer is correct |
| 12 | The tutor provides examples of the correct pattern when other forms of help<br>fail to produce an appropriate responsive action | No new interventions from the environment, Participants must study the situation |

The data helping to investigate the research questions was collected through three main instruments. Qualtrics [144] an online survey system was used to collect consent (10. 1), profile data (10. 2) and administer the pre and post-tests (10. 3); the game itself output data as the participant played and provided information on the time taken to complete tasks, and the number of times attention was paid to items and the success rate participants had with challenges (Table 9).

Table 9. Instruments Applied to Research Questions

| Research Question | Associated Instruments |
| --- | --- |
| **Research Question 1:** Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of 'over'? | Test results were collected through Qualtrics. |
| **Research Question 2:** Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile? | Test results collected through Qualtrics and environment statistics files |
| **Research Question 3:** Did performance vary by sense or mechanic? | Test results collected through Qualtrics and environment statistics files |
| **Research Question 4:** Did profile differences between participants factor in predicting performance in the VR or PC game? | Test results and profile items were collected through Qualtrics. |

**Question 1:** Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of 'over'?

To answer this question a test (10. 3) was devised to measure the participants' understanding of the senses of "over" (Figure 4). This test consisted of 3 questions for each of the 13 senses of "over" (39 items in total) and the questions were randomly presented to the participant. The same questions were used in the pre-test, before the use of the game and the post-test, after the use of the game so that the level of difficulty was equal in both tests. These tests represent the instrument for measuring the primary question.

**Question 2:** Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile?

Before the first test, the participants completed a consent and profile questionnaire (10. 1, 10. 2). This, along with the type of game environment they had used (adaptive or Static) provided the instrument through which to analyse correlations between profile items (age, gender, educational status and proficiency in English). The game itself provided data on participant interactions with the environment.

**Question 3:** Did performance vary by sense or mechanic?

Each island in the game represented a sense of over. And each island also required a specific set of actions to complete the challenge. As the participant completed the challenge the game recorded errors they made and successes resulting in the completion of the challenge. These measurements were saved into a comma-separated file for later analysis. The instrument used to compare the sense, and the mechanic participant performance was a combination of the pre, and post-test scores and the statistics collected within the environment.

**Question 4:** Did profile differences between participants factor in predicting performance in the VR or PC game?

The profile questions compared with the test results represented the instruments used to identify any profile items which could be used to predict outcomes.

Table 10. Design Framework

| | | | Non Dynamic | Dynamic | Non Dynamic | Dynamic | Non Dynamic | Dynamic |
|---|---|---|---|---|---|---|---|---|
| Environment | Diegetic | Wind | X | X | X | ✓ | X | ✓ |
| | | Light | X | X | X | ✓ | X | ✓ |
| | | Sound | X | X | X | ✓ | X | ✓ |
| | Items | Move | X | ✓ | X | X | X | X |
| | | Render | X | ✓ | X | X | X | X |
| | | Light | X | ✓ | X | X | X | X |
| | Task Type & Data<br>• Task Sense<br>• Time taken to solve 1st 2nd 3rd 4th challenge<br>• Number of Correct: Looks / Touches / Places | | **Prepositions** Generalisable to Seeking / Exploring | **Prepositions** Generalisable to Seeking / Exploring | **Prepositions** Generalisable to Selecting | **Prepositions** Generalisable to Selecting | **Prepositions** Generalisable to Sorting, Matching, Ordering | **Prepositions** Generalisable to Sorting, Matching, Ordering |
| | Enaction | | Look | | Touch | | Place | |

## 6.4 Data collection and variables

The data collection in the game was grouped into process events and waypoint events as well as the "correctness" of the actions (Figure 53). The process event data was supplemented by additional data points marking when each stage was completed.

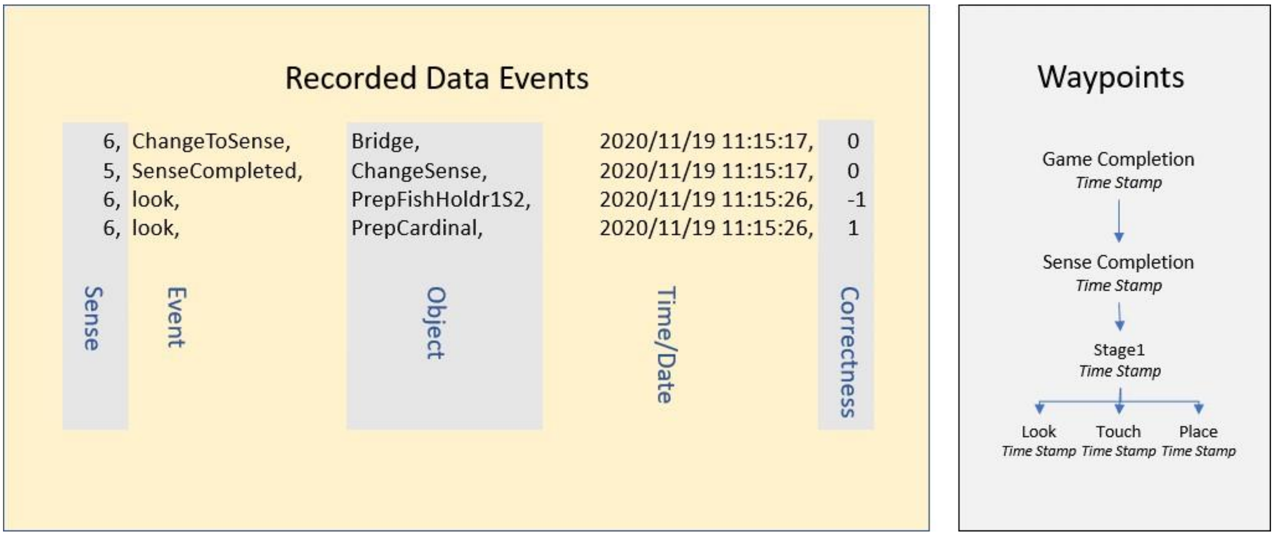


Figure 53. Game Data

The data was stored as a comma-separated value (CSV) file, so that it could be loaded directly into a relational database known as Microsoft Access for cleaning and a statistical software package known as SPSS for analysis (Table 11).

Table 11. Research Questions and Variables

| Research Question | Variables |
|---|---|
| **Research Question 1:** Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of 'over'? | Test scores from Qualtrics grouped by PC and VR game, adaptive and static. |
| **Research Question 2:** Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile? | Test scores and profile data from Qualtrics grouped by PC and VR game, adaptive and Static. Game data files. |
| **Research Question 3:** Did performance vary by sense or mechanic? | Test scores and profile data from Qualtrics grouped by PC and VR game, adaptive and Static. Game data files. |

| | |
|---|---|
| **Research Question 4:** Did profile differences between participants factor in predicting performance in the VR or PC game? | Test scores and profile data from Qualtrics grouped by PC and VR game, adaptive and Static. Game data files. |

**Grouping Mechanics:** Based on the description of the mechanic the actions required in the challenge ( Table 3) determine their grouping. However, there is an element of subjectivity in this allocation and the measurements based on mechanic groups may be incorrect as a result. To validate this grouping factor analysis was used to understand the mechanic effect on the correct attention score (Section 8. 7).

# 7 Study

## 7.1 Introduction

This research uses a repeated measures design measuring the same group with the same questions separated by experimental conditions. The experimental conditions were adaptive or Static environments on either a PC or VR platform. In all cases the game tasks remained the same (4. 7). The following analysis section describes:

- Data sets and data preparation ( 8. 2, 8. 3)
- Descriptive statistics for the participants (8. 4)
- Descriptive statistics for the questions used in the pre and post-tests (8. 5)
- Descriptive statistics for the environments (8. 6)
- Inferential analysis of test scores (8. 7)
- Inferential analysis of the tasks dataset (environment) and question dataset relating to performance (8. 8)
- Inferential analysis of time relating to tasks and performance (8. 9)
- Inferential analysis of profile data relating to performance (8. 9 )

The analysis process can be visualised in Figure 54.

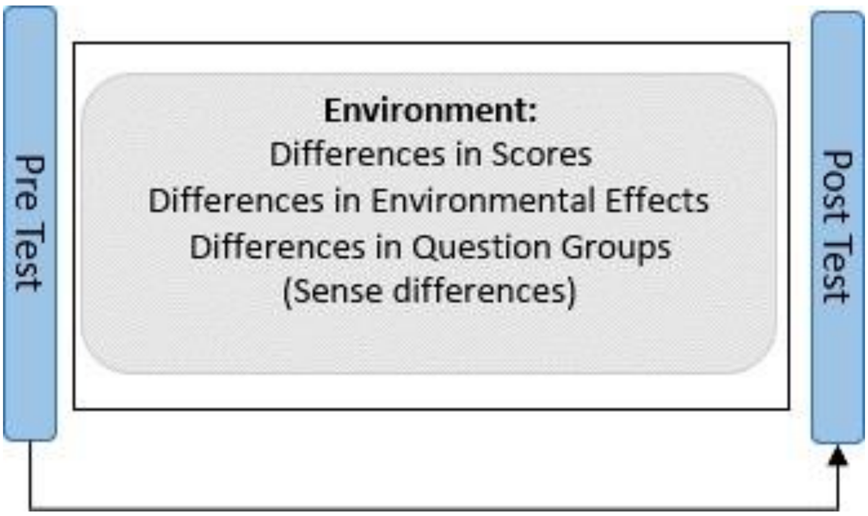


Figure 54. Analysis Process

## 7.2 Data Sets

There were four data sets analysed. The pre and post-test scores, participant profiles and the data collected from each of the environmental conditions (Figure 55).


Figure 55. Datasets

## 7.3 Data preparation

This section describes where the data for analysis came from and how it was manipulated to ensure that duplicates and errors were omitted from the analysis.

The pre and post-tests generate a comma-separated text file which was imported into Access for checking and grouping.  The environment generated a comma-separated text file for each completed task, "Look", "Touch", and "Place", which was also imported into Access for checking and grouping.  A list of respondents emails which appeared in the pre and post-test scores files, the profile files and the environment statistics files were used to cross-check the tables in Access (Figure 56).

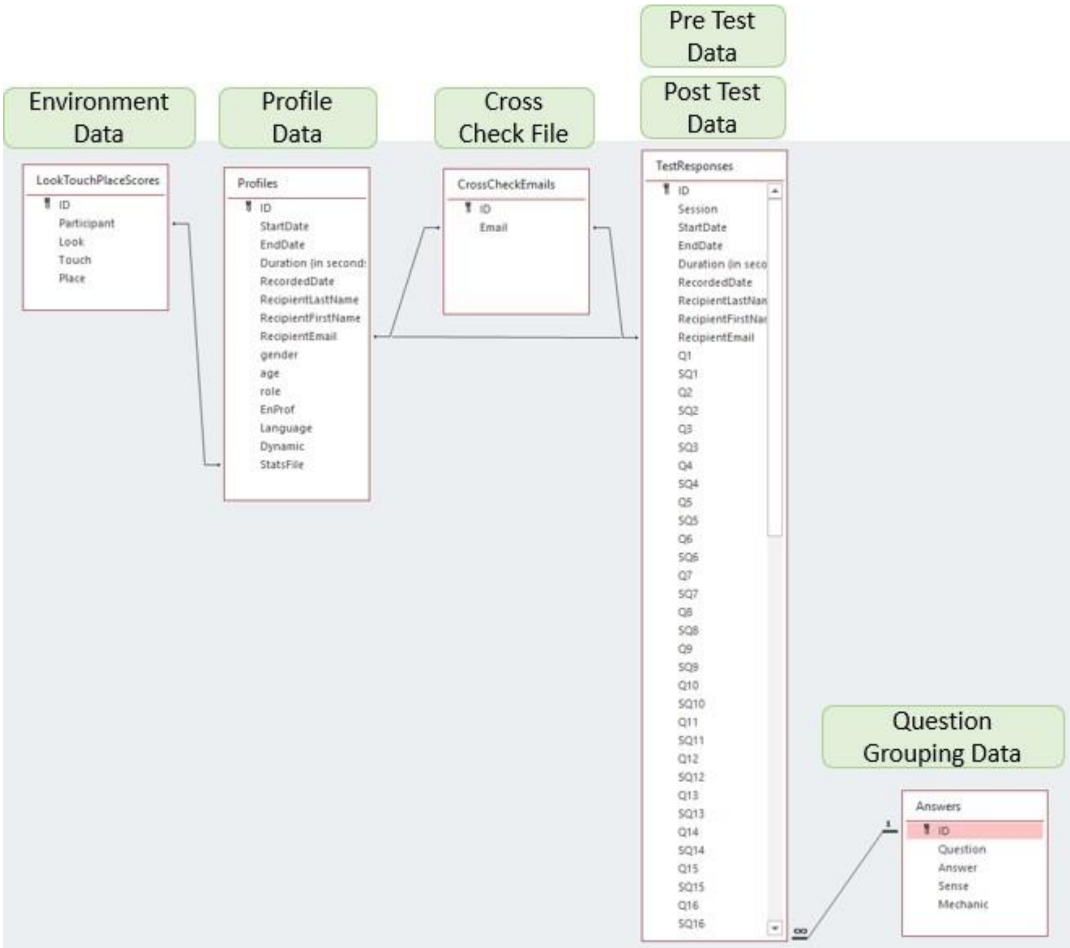


Figure 56. Data Relationships

Queries for each research question were then run to provide the numbers for statistical analysis. The results of the queries were then imported to SPSS 27 for analysis.

Environmental data were imported individually into the database and then grouped in a single table. This table was then linked to the profile data and to a table which identified senses of over. The links used were exclusive to ensure that no "result" data was counted twice, and no duplicate participant data would be included in the analysis.

All analysis data was tested for skewness to ensure it represents a normal distribution. For example, the pre and post-test scores for the static PC group represented on a histogram (Figure 57), a test for skewness (Table 12) and a quantile-quantile plot (Figure 58) suggests that the data is normally distributed. The test for skewness shown in Table 12 sits within the range 1 and -1 and is less than double the standard error suggesting that the data is normally distributed.

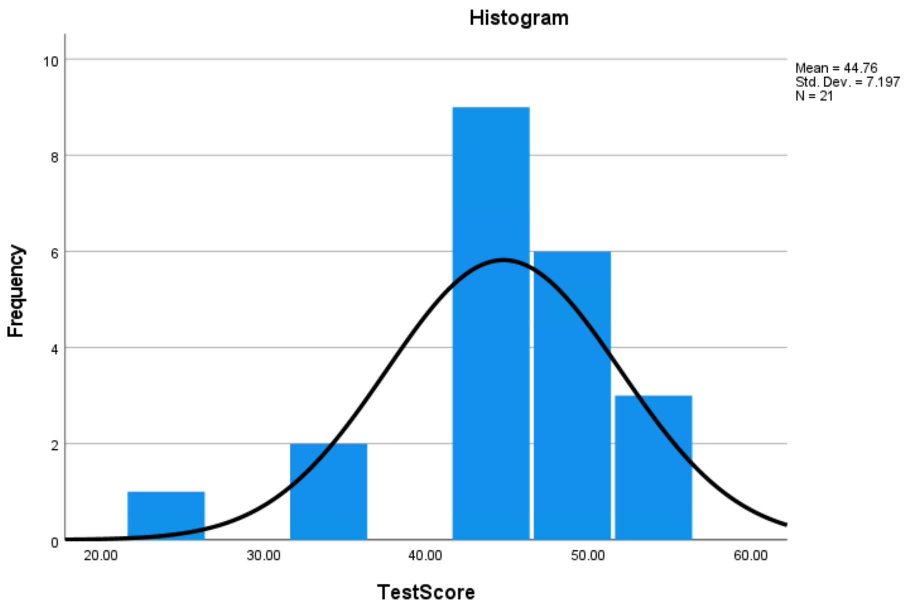


Figure 57. Histogram of Test Results

Table 12. Test for Skewness

**Descriptive Statistics**

TestScore

| | | |
|---|---|---|
| N | Valid | 21 |
| | Missing | 0 |
| Skewness | | -1.470 |
| Std. Error of Skewness | | .501 |

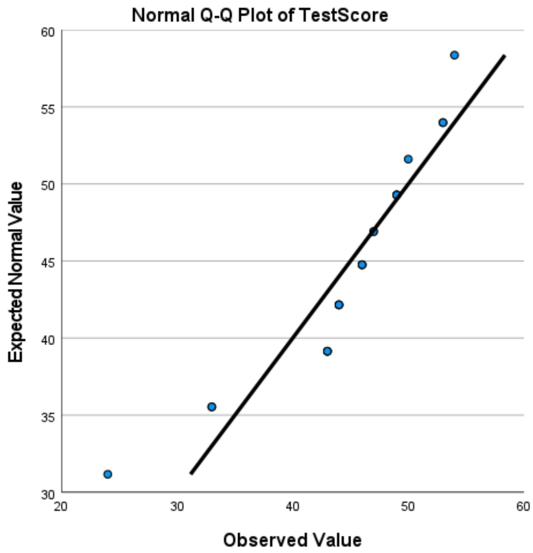


Figure 58. Q-Q Plot of Test Scores

Where data is not normally distributed a transform variable was created using the formula for positive skewness:

Equation 1

$$LogScore = Log10(Score\ Value)$$

For negative skewness reflection was used:

Equation 2

$$LogScore = Log10(maxvalue + 1 - Score\ Value)$$

The resulting normalised values were then used for parametric analysis.

Where skewness is calculated the evaluation used was:

- If skewness is less than -1 or greater than 1, the distribution is highly skewed.
- If skewness is between -1 and -0.5 or between 0.5 and 1, the distribution is moderately skewed.
- If skewness is between -0.5 and 0.5, the distribution is approximately symmetric

Where t-tests showed a statistically significant result the effect size was calculated and evaluated using Cohen’s D rules of thumb: 0.2 small, 0.5 medium, 0.8 large [145].

## 7.4 Descriptive Statistics: Participants

During the COVID-19 lockdown university participants who speak English as a second language were invited to participate in the research remotely using the PC version of the game (Figure 80). From 80 responses 40 were able to participate (Figure 59). When COVID-19 restrictions were lifted university participants who speak English as a second language and who attended the Essex University campus were invited to participate in the Virtual Reality version of the game. They were approached through a presentation by the researcher in one of their lectures or through posters in common areas of the campus or emailed to distribution lists (Figure 80). From 22 responses 20 participated (Figure 59). Overall, from a total of 102 responses 34 were uncontactable after the initial response, 14 did not have the needed PC for the remote research, and during the VR session, 4 participants felt nauseous and were unable to continue (See “Other” in Figure 59). VR Participants were informed at the beginning of the research both through the participant information sheet and by the researcher that the oculus in some cases can cause some dizziness and maybe some nausea. The researcher explained that should this occur, they should stop using the headset and could if they wished to, stop their research session. Of 20 participants 4 had a specific issue with nausea and ended the research session. In all 4 cases, the participants went on to complete the PC version of the game without any continuing negative effects. It may be interesting to note that three of the 4 participants who had an issue with nausea wore glasses. As the oculus has adjustable lenses and the position of the headset on the head is critical to having a clear focus it may be that the oculus needs to be more precisely positioned on the head of the participant if they wear glasses. Some of the participants wore their glasses inside the headset however this did not prevent them from feeling nauseous.

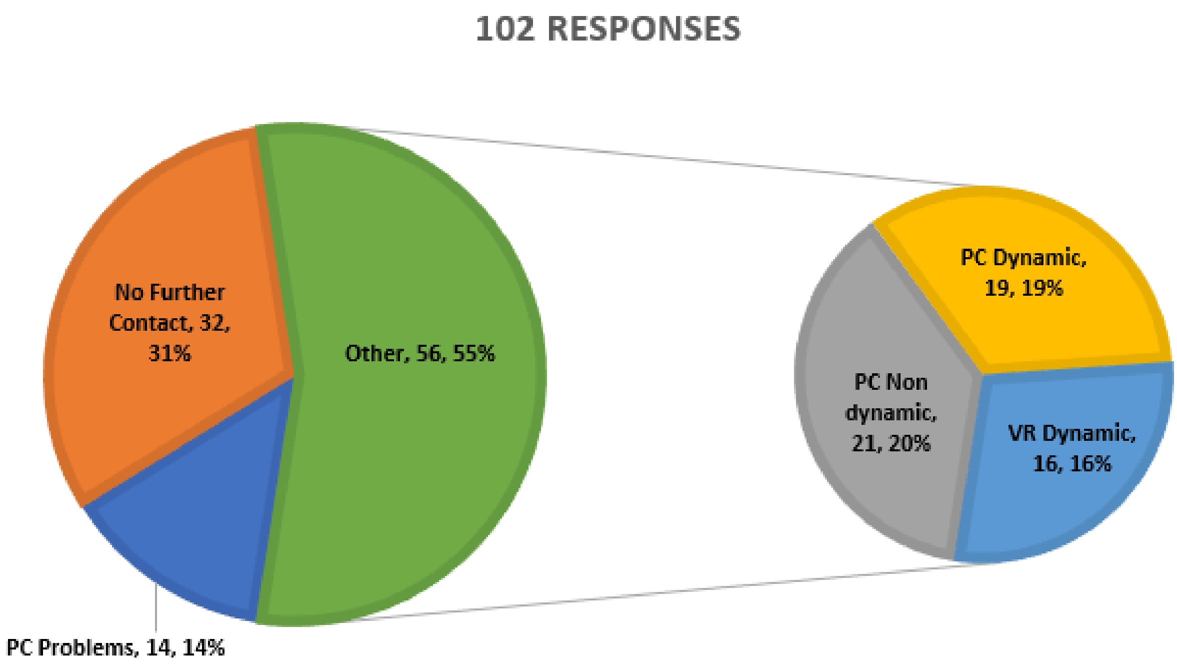


Figure 59. Responses to Invitation

A total of 56 University participants (26 male, 30 female), speaking 22 different languages (Figure 60) and who speak English as a second language, were recruited to the study by email, presentation or poster. These either invited them to participate in the online PC game version or the Virtual Reality version of the research. No first language selection criteria were used (Figure 60) however, these participants had attended or were attending, an English-speaking university. This was used as a guide to English proficiency which was further self-reported in the profile questionnaires (10. 2). Participants did not need to be in England to take part because the research was conducted remotely. At the time of this stage of the research, the Covid 19 pandemic was ongoing, and many participants had returned to their home countries. Participation was entirely voluntary, and all participants were offered a £10 Amazon voucher if they completed the consent form (10. 1), the profile questionnaire (10. 2), the pre and post-tests (10. 3) as well as the game.

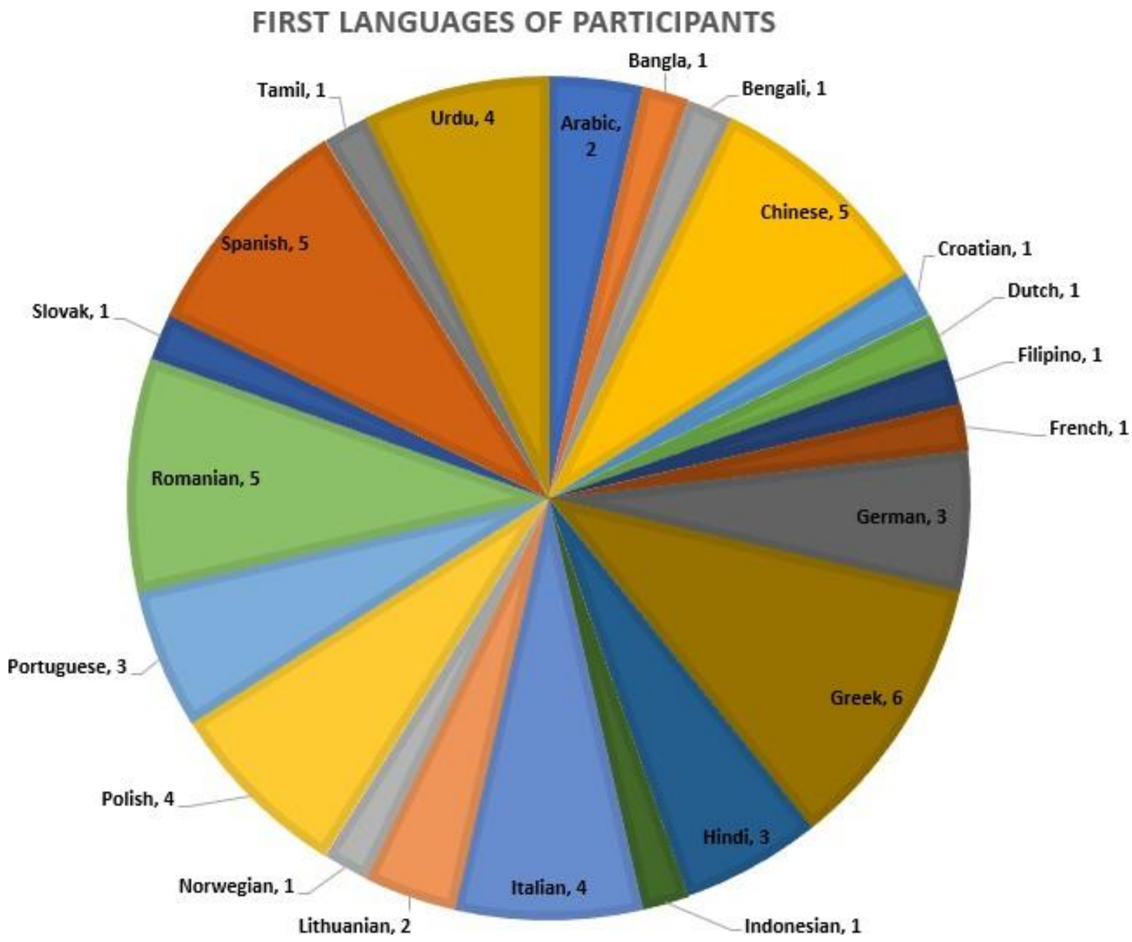


Figure 60. First Language of Participants

All participants were allocated to adaptive and Static environments randomly.

Ethical approval was received from the University of Essex CSEE ethics committee for both the PC (ETH2021-0952) and the VR (ETH2021-1576) studies, and all participants received a participant information sheet outlining what information was going to be collected and how it would be used (Appendix 10. 4).

The random allocation of environments resulted in more male participants for the PC adaptive and more female participants for the PC static environments (Figure 61). As a result of the restrictions caused by COVID-19 the PC experimental condition was completed remotely however, the virtual reality environment required the participants to be present at the university and this may have skewed the gender split for the virtual reality environment as the responses to the invitations were overwhelmingly female.

The age distribution of participants represents the university population heavily biased towards the 18 to 24 age group (Figure 62) and proficiency in English was perhaps not surprisingly skewed towards Fluent (Figure 63).

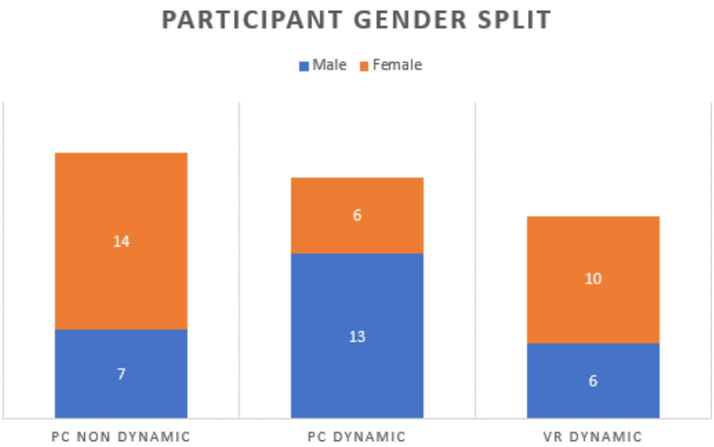


Figure 61.Gender Distribution

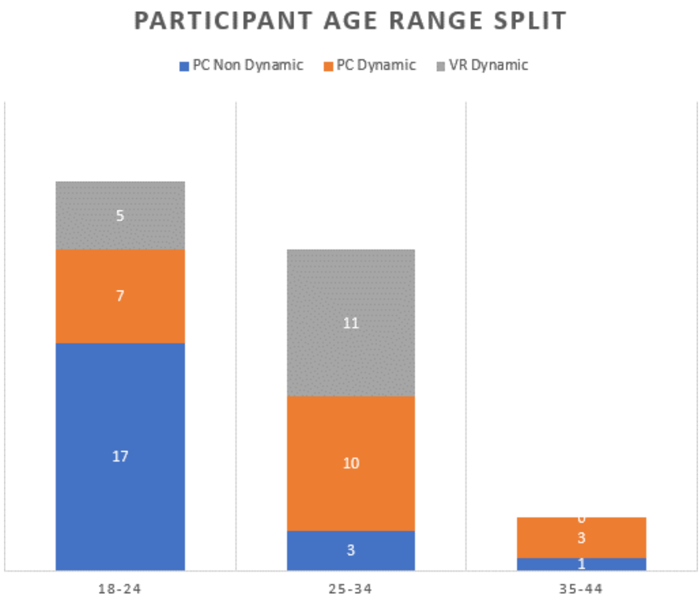


Figure 62. Age Distribution

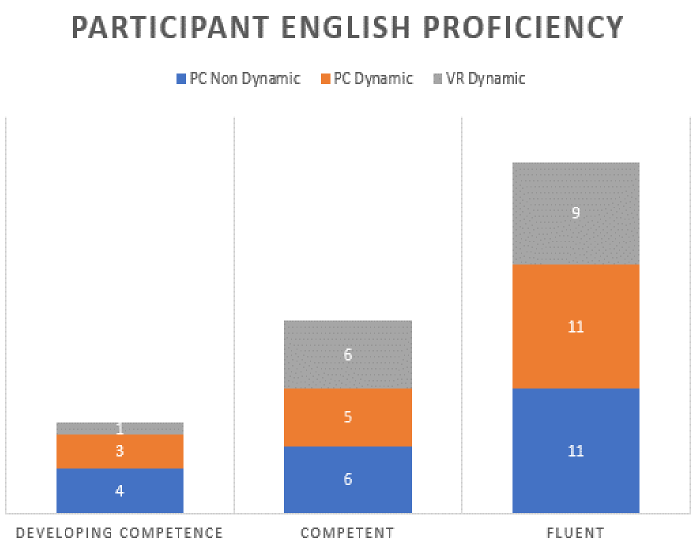


Figure 63. English Proficiency Distribution

## 7.5 Descriptive Statistics: Questions

The questions consisted of 13 senses of “Over” each with three different questions. The minimum score for each sense was zero and the maximum score was 3 (all three questions relating to that sense correctly answered).

In Table 13 the sense questions are grouped representing both pre and post-tests (N is double the number of participants). All 56 participants across all of the conditions answered all of the questions.

Table 13. PC Participants

**Descriptive Statistics[a]**

| | N | Mean |
|---|---|---|
| Proto | 80 | 2.32 |
| Excess1 | 80 | .45 |
| OtherSide | 80 | 1.83 |
| Completion | 80 | 2.34 |
| Transfer | 80 | 2.52 |
| Control | 80 | 1.71 |
| Temporal | 80 | 2.73 |
| Cover | 80 | 1.76 |
| Focus | 80 | 2.18 |
| Preference | 80 | 2.94 |
| Reflexive | 80 | 2.64 |
| Repetition | 80 | 2.93 |
| Excess2 | 80 | 2.60 |
| Valid N (listwise) | 80 | |

a. PC = Yes

VR Participants

**Descriptive Statistics[a]**

| | N | Mean |
|---|---|---|
| Proto | 32 | 2.44 |
| Excess1 | 32 | .00 |
| OtherSide | 32 | .00 |
| Completion | 32 | .50 |
| Transfer | 32 | 2.16 |
| Control | 32 | .09 |
| Temporal | 32 | 2.81 |
| Cover | 32 | 2.22 |
| Focus | 32 | 2.31 |
| Preference | 32 | 2.94 |
| Reflexive | 32 | 2.72 |
| Repetition | 32 | 2.94 |
| Excess2 | 32 | 2.81 |
| Valid N (listwise) | 32 | |

a. PC = No

## 7.6 Descriptive Statistics: Teaching Environments

The environment measures are measures of participant activity in response to environmental change (adaptive environment) or lack of change (Static environment) as determined by the proposed framework Table 15. These measures can be compared in the adaptive and static environments as well as to the pre and post-test scores and the profile variables.

Table 14. Framework Values and Actions

| | | | Non Dynamic | Dynamic | Non Dynamic | Dynamic | Non Dynamic | Dynamic |
|---|---|---|---|---|---|---|---|---|
| Environment | Diegetic | Wind | X | X | X | ✓ | X | ✓ |
| | | Light | X | X | X | ✓ | X | ✓ |
| | | Sound | X | X | X | ✓ | X | ✓ |
| | Items | Move | X | ✓ | X | X | X | X |
| | | Render | X | ✓ | X | X | X | X |
| | | Light | X | ✓ | X | X | X | X |
| | Task Type & Data<br>• Task Sense<br>• Time taken to solve 1st 2nd 3rd 4th challenge<br>• Number of Correct: Looks / Touches / Places | | **Prepositions** Generalisable to Seeking / Exploring | **Prepositions** Generalisable to Seeking / Exploring | **Prepositions** Generalisable to Selecting | **Prepositions** Generalisable to Selecting | **Prepositions** Generalisable to Sorting, Matching, Ordering | **Prepositions** Generalisable to Sorting, Matching, Ordering |
| | Enaction | | Look | | Touch | | Place | |

The descriptive statistics for environmental events are described in Table 15. They are split into PC and VR groups shown in Table 16 and  Table 17 where all cases were represented. However, some actions such as "sense skipped" or "stage failure" is not present in all completed data sets because they were not triggered. Only the events "look", "touch" and "place" are driven by the participant's actions within the challenges. All other events are intended to mark time between significant waypoints such as completing a sense or failing at a stage.

Table 15. Event Descriptions

| Event | Description |
|---|---|
| **Change To Sense** | Marks the moment the next sense challenge is started |
| **Look** | Ray casts from the mouse or VR headset have intersected an item |
| **Touch** | Either mouse down or VR hand grab an item |
| **Place** | Item released from mouse or VR hand grab |
| **Sense Complete** | All tasks completed on the island |
| **Sense Skipped** | Island skipped, specifically the lifebuoy in the game was touched |
| **Stage Failure** | A task was incorrectly completed |
| **Stage Success** | A task was correctly completed |

Table 16. Descriptive Statistics PC Environmental Events

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Look Score | 40 | -1407 | 949 | -69.85 | 439.177 |
| Touch Score | 40 | 34 | 160 | 63.93 | 27.951 |
| Place Score | 40 | 47 | 179 | 103.82 | 35.584 |
| Valid N (listwise) | 40 | | | | |

a. PC = Yes

Table 17. Descriptive Statistics VR Environmental Events

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Look Score | 16 | -290 | 1624 | 970.88 | 537.588 |
| Touch Score | 16 | 83 | 166 | 129.13 | 20.379 |
| Place Score | 16 | 67 | 110 | 82.94 | 13.714 |
| Valid N (listwise) | 16 | | | | |

a. PC = No

All but one action in both environments is normally distributed and can be analysed with parametric tests. The place action in the VR environment shows a positive skew however it also has very few actions per participant to be significant.

A total of 137,254 events were captured from 56 completed games. The different approaches to capturing events based on the platform used are described in section 4. 7 and are the cause of the difference in the number of events captured (Table 18).

Table 18. Total Environment Events

**Descriptive Statistics**

| PC | | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| No | Count Of Score | 16 | 1470.00 | 8985.00 | 4282.4375 | 1561.56076 |
| | Valid N (listwise) | 16 | | | | |
| Yes | Count Of Score | 40 | 367.00 | 6680.00 | 1141.2000 | 1305.14980 |
| | Valid N (listwise) | 40 | | | | |

## 7.7 Inferential Test Score Analysis

This section describes the analysis of the session test scores for each condition (Figure 64). It describes the significant differences between the mean scores for the pre and post-tests overall, and then the mean scores for pre and post-tests broken down by condition i.e., those relating to the PC environment and those relating to the VR environment and is intended to look for evidence to help understand the first research question (Table 1). Paired samples t-tests are used as the before and after tests results are taken from the same individuals.

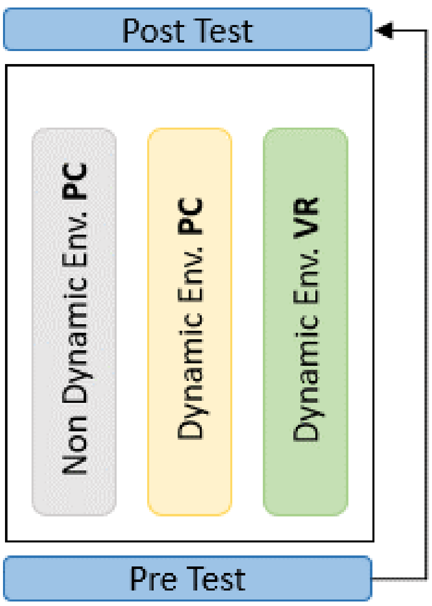


Figure 64. All Conditions Tested

Table 1. Research Questions

| | |
|---|---|
| **Research Question 1** | Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of 'over'? |
| **Research Question 2** | Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile? |
| **Research Question 3** | Did performance vary by sense or mechanic? |
| **Research Question 4** | Did profile differences between participant's factor in predicting performance in the VR or PC game? |

The normality of pre and post-test scores was confirmed using Q-Q Plots (Figure 65, Figure 66, Figure 67, Figure 68). 19 participants completed a single session with the adaptive PC environment. Their pre and post-test mean scores (Table 19) were lower before using the environment (M=41.32, SD=6.92) than after (M=42.84 SD=8.15). This improvement was too small to be statistically significant, the difference between the means was only 1.52 with p 0.128>0.05 (Table 20).

Table 19. Static PC Mean Test Scores

**Paired Samples Statistics**

| | | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Pair 1 | Session1 | 43.57 | 21 | 6.787 | 1.481 |
| | Session2 | 44.71 | 21 | 7.191 | 1.569 |

Table 20. Adaptive PC Paired T-Test

**Paired Samples Test**

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference Lower | Upper | | | |
| Pair 1 | Session1 - Session2 | -1.526 | 4.168 | .956 | -3.535 | .483 | -1.596 | 18 | .128 |

21 participants completed a single session with the Static PC environment. Their pre and post-test mean scores (Table 19) were lower before using the environment (M=43.57, SD=6.79) than after (M=44.71 SD=7.19). This improvement was statistically significant, the difference between the means was -1.14 with p 0.022<0.05 (Table 21, Table 22).

Table 21. Static PC Paired T-Test

**Paired Samples Test**

| | | Paired Differences | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval of the Difference | | | | |
| | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Pair 1 | Session1 – Session2 | -1.143 | 2.104 | .459 | -2.101 | -.185 | -2.489 | 20 | .022 |

Table 22. Adaptive VR Mean Test Scores

**Paired Samples Statistics**

| | | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Pair 1 | PreTestScore | 22.94 | 16 | 3.890 | .972 |
| | PostTestScore | 24.94 | 16 | 2.380 | .595 |

The Cohen's D test (Table 23) indicates that the effect size of the difference was medium (point estimate -0.543)

Table 23. Cohen's D Effect Size PC Static

**Paired Samples Effect Sizes**

| | | | Standardizer[a] | Point Estimate | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower | Upper |
| Pair 1 | Session1 – Session2 | Cohen's d | 2.104 | -.543 | -.996 | -.078 |
| | | Hedges' correction | 2.145 | -.533 | -.978 | -.077 |

a. The denominator used in estimating the effect sizes.

Cohen's d uses the sample standard deviation of the mean difference.

Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

16 participants completed a single session with the adaptive VR environment. Their pre and post-test mean scores (Table 22) were lower before using the environment (M=22.94, SD=3.89) than after (M=24.94 SD=2.38). This improvement was statistically significant, the difference between the means was -2.00 with p 0.004<0.05 (Table 24).

Table 24. Adaptive VR Paired T-Test

**Paired Samples Test**

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | PreTestScore - PostTestScore | -2.000 | 2.394 | .599 | -3.276 | -.724 | -3.341 | 15 | .004 |

The Cohen's D test (Table 25) indicates that the effect size of the difference was strong (point estimate -0.835)

Table 25. Cohen's D Effect Size VR Adaptive

**Paired Samples Effect Sizes**

| | | | Standardizer[a] | Point Estimate | 95% Confidence Interval Lower | Upper |
|---|---|---|---|---|---|---|
| Pair 1 | PreTestScore - PostTestScore | Cohen's d | 2.394 | -.835 | -1.398 | -.253 |
| | | Hedges' correction | 2.456 | -.814 | -1.362 | -.246 |

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.
Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

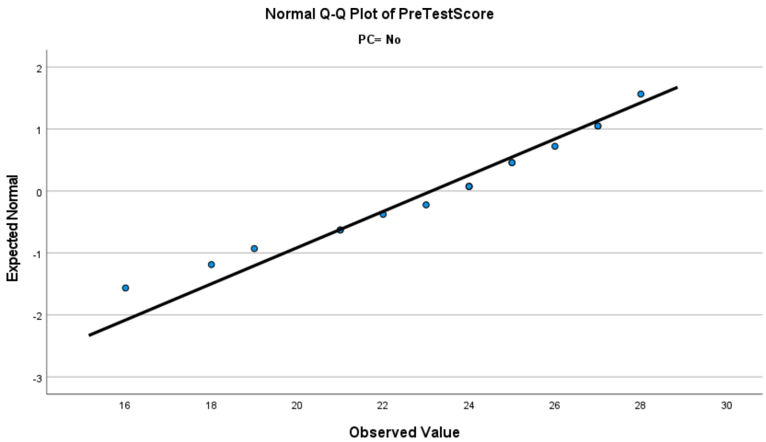


Figure 65. VR Pre-test Results

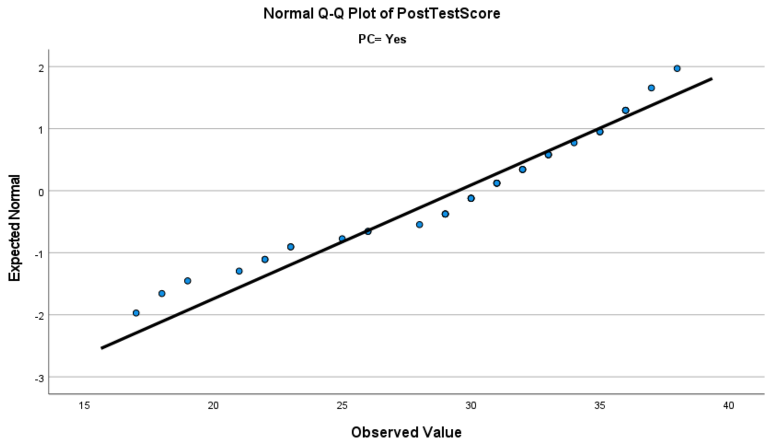


Figure 66. PC Post-test Results

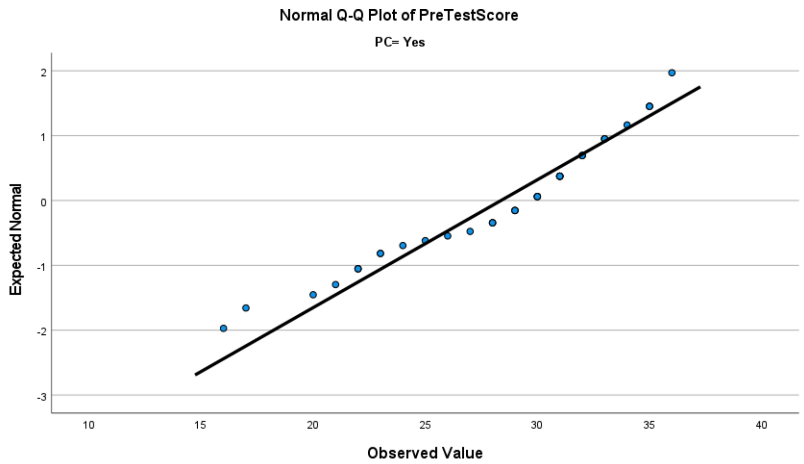


Figure 67. PC Pre-test Results

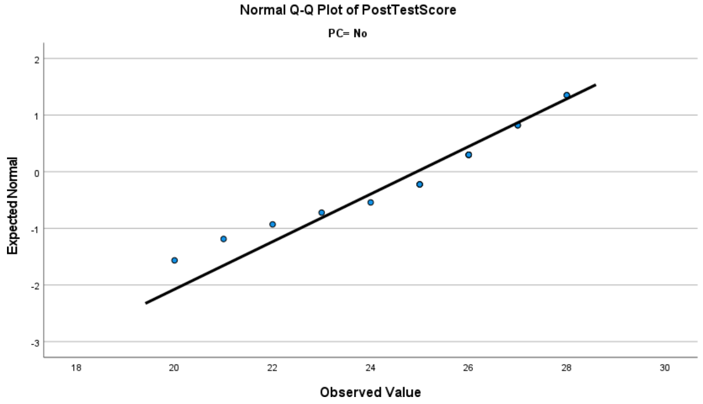


Figure 68. VR Post-test Results

A further comparison of test scores between the two environments (Table 26) which indicates a statistically significant difference i.e., VR and PC (Static) shows that the PC static environment appears to have greater statistical significance (PC Non = p0.003<0.05 VR = p0.04<0.05) (Table 27).

Table 26. PC Non & VR Adaptive

**Paired Samples Statistics**

| Adaptive | | | Mean | N | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|---|
| N | Pair 1 | PreTestScore | 29.67 | 21 | 5.003 | 1.092 |
| | | PostTestScore | 31.33 | 21 | 5.092 | 1.111 |
| Y | Pair 1 | PreTestScore | 22.94 | 16 | 3.890 | .972 |
| | | PostTestScore | 24.94 | 16 | 2.380 | .595 |

Population Pyramid Frequency charts show the test score differences ("PC yes" shows the Static PC scores and "PC no" shows the VR test scores) (Figure 69, Figure 70) with PC test scores generally higher as previously shown in the mean values (Table 20, Table 22).

Table 27. PC Non and VR Adaptive Paired T-Test

**Paired Samples Test**

| | | | Paired Differences | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 95% Confidence Interval of the Difference | | | | |
| Adaptive | | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| N | Pair 1 | PreTestScore - PostTestScore | -1.667 | 2.221 | .485 | -2.678 | -.656 | -3.439 | 20 | .003 |
| Y | Pair 1 | PreTestScore - PostTestScore | -2.000 | 2.394 | .599 | -3.276 | -.724 | -3.341 | 15 | .004 |

The following population frequencies show results for PC on the left (PC Yes) and results for VR on the right (PC No).

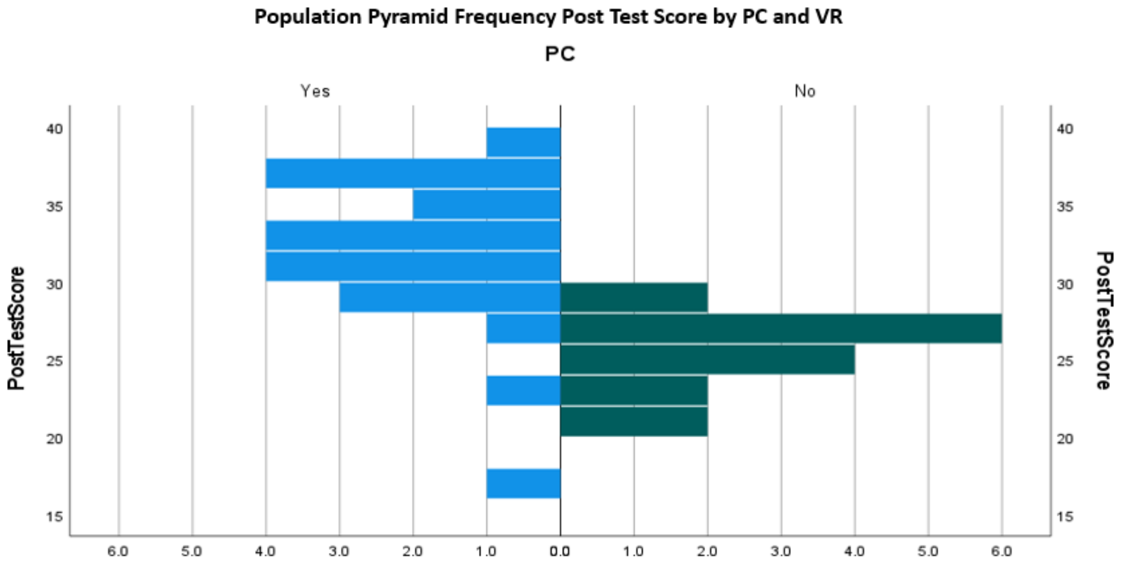


Figure 69. PC Static Versus VR Post-test Scores

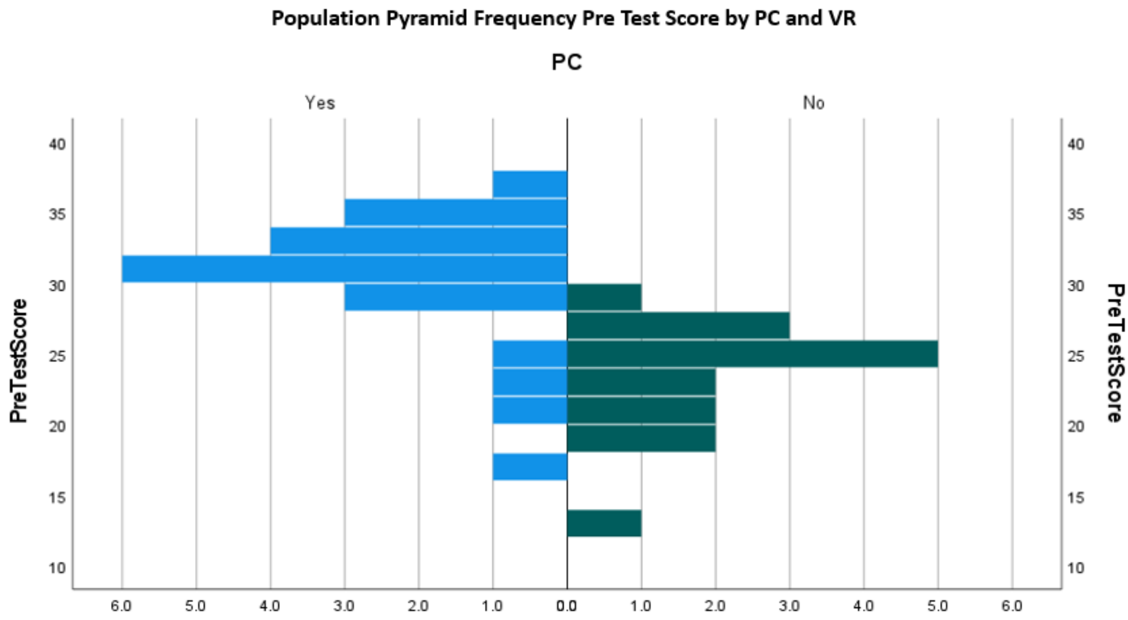


Figure 70. PC Static Versus VR Pre-test Scores

The PC test scores were higher overall than the VR test scores with PC Static higher than Adaptive (Figure 71).

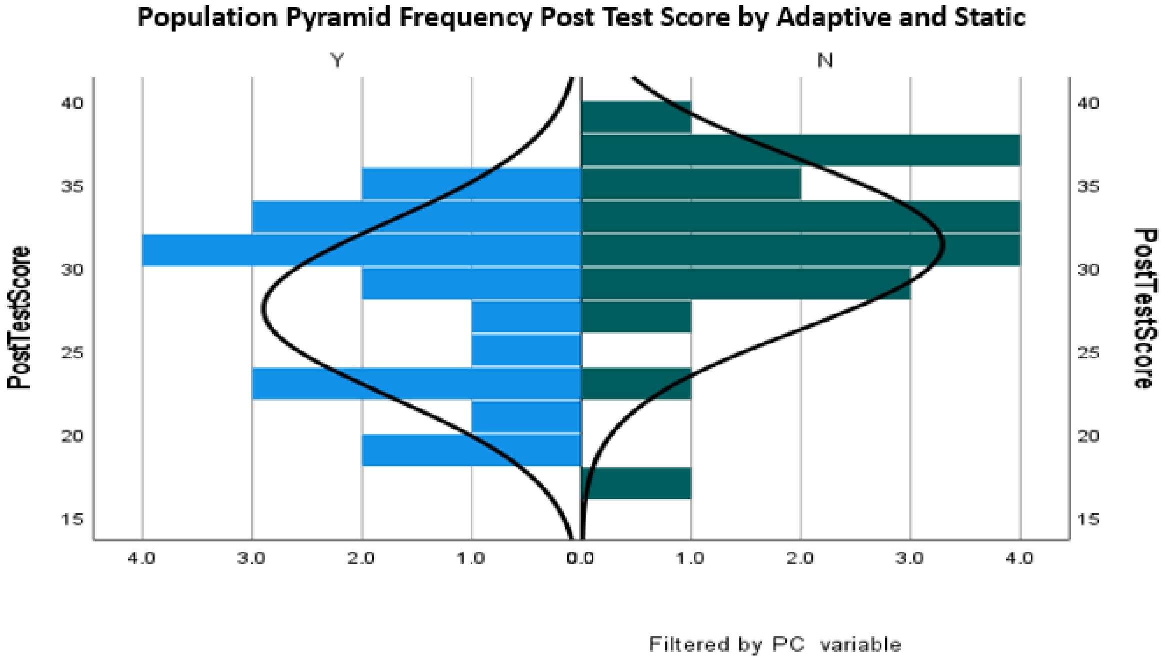


Figure 71. PC Adaptive and Static Pre-Test Scores

**Summary:** The use of all three environments resulted in the improvement of test scores. Two environments produced a statistically significant increase, these were the PC static environment and the VR adaptive environment. The PC static environment had a moderate effect size which means that it had some effect on the post-test result. The VR had a strong effect size which means it had a strong effect on the post-test result. The mean scores for the remote tests were generally higher than the mean scores for the VR tests, and this was true for both pre and post-test scores.

**Discussion:** While the challenges in both environments, we're the same and the tests were the same, the conditions under which the challenges and tests were undertaken differed. There is the possibility that remote test results were the product of co-constructed consensus (i.e., the result of discussion and consensus of a group) rather than the work of an individual. Even with this confounding factor the VR the condition produced the greatest impact on post-test scores. This result suggests that the environmental changes were sufficient to guide the players and that this guidance supported the players' ability to demonstrate their new understanding of the concepts in the challenges. Given that the design methods described in chapter 4 were used in both the static and adaptive VR games, it appears likely that the adaptive nature of the game had a positive effect on the player. Further research may reveal to what extent test conditions affected the results.

Table 1. Research Questions

| | |
|---|---|
| **Research Question 1** | Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of ‘over’? |
| **Research Question 2** | Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile? |
| **Research Question 3** | Did performance vary by sense or mechanic? |
| **Research Question 4** | Did profile differences between participant’s factor in predicting performance in the VR or PC game? |

There was no statistically significant difference between pre and post-test scores of the groupings: gender, English proficiency and Education level in the PC and VR groups as determined by one-way ANOVA (9. 9, Table 50, Table 51, Table 52, Table 53). There was a statistically significant difference between the pre and post-test scores of age groupings within the 16 participants (Table 28) using the VR environment, as determined by one-way ANOVA (Analysis of Variance) (Table 29), (F(5.385)p 0.36 <0.05). ANOVA was used for this analysis as the age groups were independent i.e., this did not include repeated measures. The differences are also shown by the population pyramid frequency charts (Figure 72, Figure 73).

Table 28. Age Frequency VR

**age**

| | | Frequency | Per cent | Valid Per cent | Cumulative Per cent |
|---|---|---|---|---|---|
| Valid | 18-24 | 6 | 37.5 | 37.5 | 37.5 |
| | 25-34 | 10 | 62.5 | 62.5 | 100.0 |
| | Total | 16 | 100.0 | 100.0 | |

Table 29. Comparison of Age Performance VR

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| PreTestScore | Between Groups | 63.038 | 1 | 63.038 | 5.385 | .036 |
| | Within Groups | 163.900 | 14 | 11.707 | | |
| | Total | 226.938 | 15 | | | |
| PostTestScore | Between Groups | 23.438 | 1 | 23.438 | 5.335 | .037 |
| | Within Groups | 61.500 | 14 | 4.393 | | |
| | Total | 84.938 | 15 | | | |

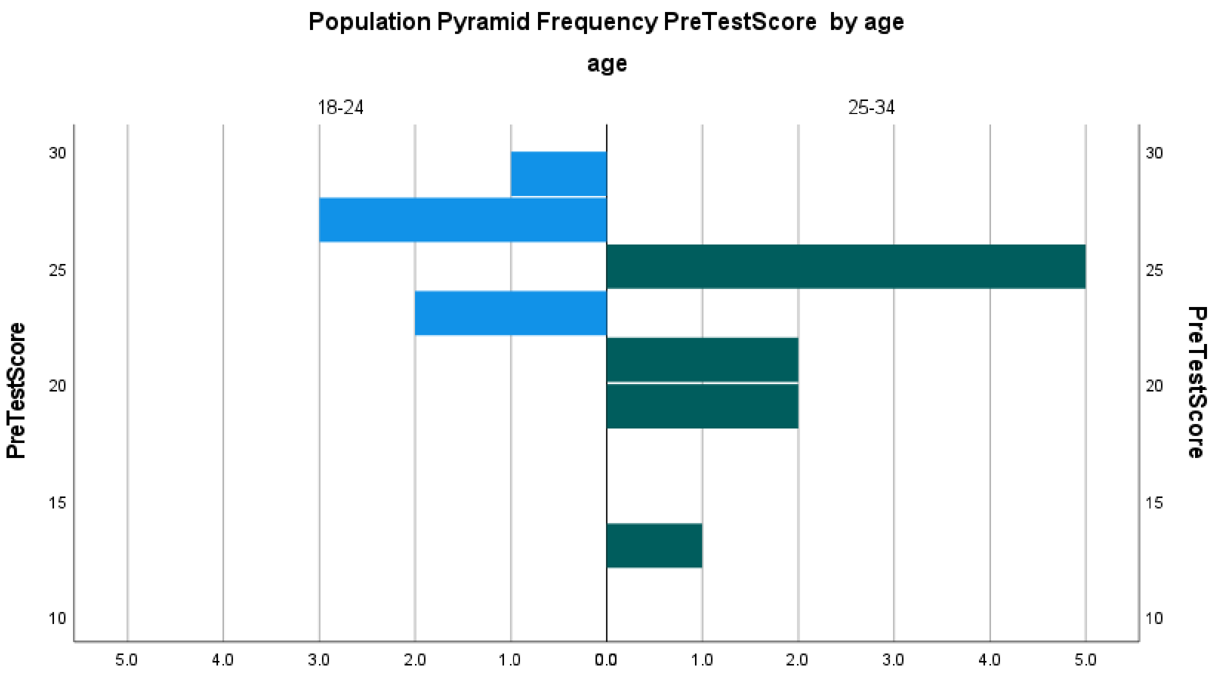


Figure 72. Pre-Test VR Age Comparison

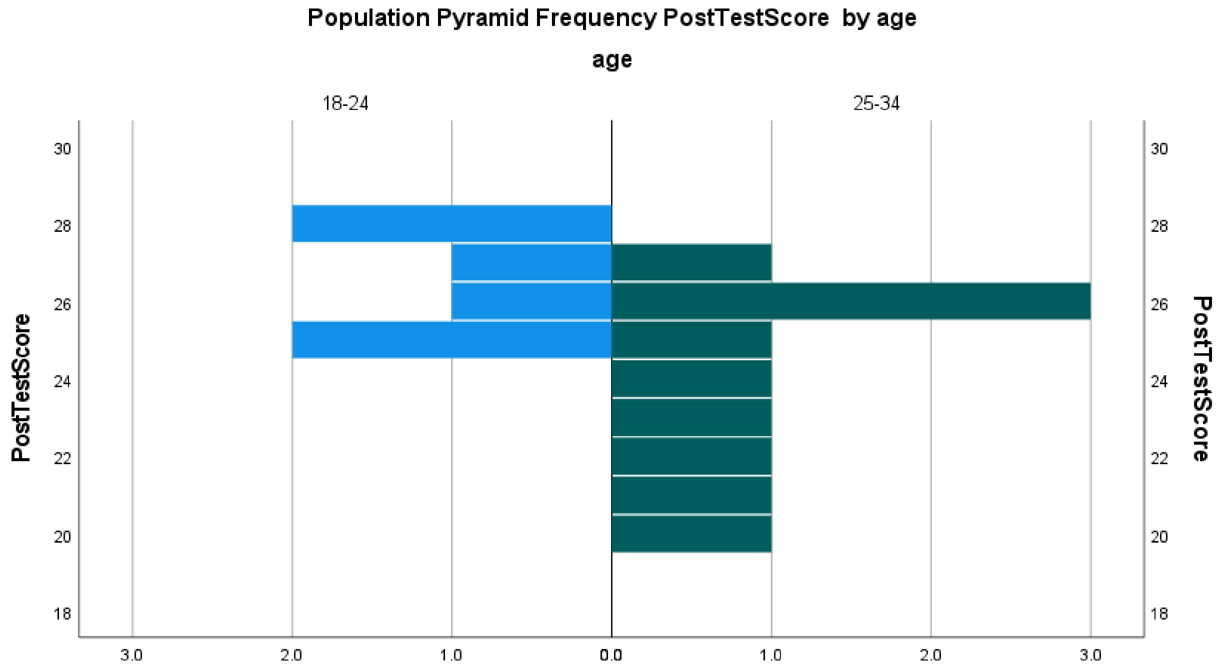


Figure 73. Post-test VR Age Comparison

**Summary:** When comparing the test results broken down by age, it appears that in the VR environment younger participants performed significantly better than older participants.

**Discussion:** Age may be a factor when using more recent technology such as VR, however, in this research there were only 16 participants in the VR condition, and it may be incorrect to draw conclusions from the differences in such a small sample. As the VR condition was controlled by the researcher it seems unlikely that other factors were causing the difference in performance by age and the comparison does appear to warrant further study.

## 7.8 Inferential Environment Analysis: PC Static and VR Conditions

This section describes the analysis of the environmental scores for the conditions which showed a significant difference in test scores and compares them to profile items and test scores (Figure 74). It describes the relationship between the actions taken in the environment and the participants.

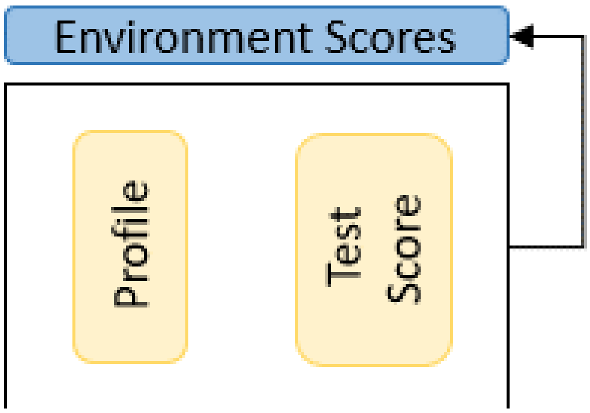


Figure 74.Analysis of Environment – Profile / Test Score

Table 1. Research Questions

| | |
|---|---|
| **Research Question 1** | Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of 'over'? |
| **Research Question 2** | Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile? |
| **Research Question 3** | Did performance vary by sense or mechanic? |
| **Research Question 4** | Did profile differences between participants' factor in predicting performance in the VR or PC game? |

The time taken to complete the PC Adaptive environment was tested and found to be normally distributed (Table 30)

Table 30. PC Adaptive Env. Time

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| Time | 19 | 5.00 | 98.00 | 37.1579 | 43.19370 | .767 | .524 |
| Valid N (listwise) | 19 | | | | | | |

Table 31. PC Static Env. Time

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| Time | 21 | 5.00 | 50.00 | 21.5238 | 11.20990 | .846 | .501 |
| Valid N (listwise) | 21 | | | | | | |

The time taken to complete the VR environment was tested and also found to be normally distributed (Table 32)

Table 32. VR Env. Time

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| Time | 16 | 18.00 | 98.00 | 42.1250 | 29.66227 | .807 | .564 |
| Valid N (listwise) | 16 | | | | | | |

The mean completion duration for the PC Adaptive environment was M=37 minutes, the mean completion time for the PC static environment was M=21.5 minutes and the mean completion time for the VR environment was M=42 minutes.

16 participants completed a single session in the VR environment (Table 33). Their actions scores were "look" (M=1013, SD=442) "touch" (M=129, SD=20) and "place" (M=83, SD=14). 21 participants completed a single session in the Static PC environment (Table 34). Their actions scores were "look" (M=-272, SD=330) "touch" (M=65, SD=25) and "place" (M=109, SD=25).

Table 33. Descriptive Statistics for Action Scores

**Descriptive Statistics**

| PC | | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| No | Look Score | 16 | 182 | 1624 | 1013.38 | 448.117 |
| | Touch Score | 16 | 83 | 166 | 129.13 | 20.379 |
| | Place Score | 16 | 67 | 110 | 82.94 | 13.714 |
| | Valid N (listwise) | 16 | | | | |
| Yes | Look Score | 21 | -1407 | 293 | -272.29 | 330.958 |
| | Touch Score | 21 | 40 | 160 | 64.76 | 25.345 |
| | Place Score | 21 | 71 | 179 | 108.86 | 25.523 |
| | Valid N (listwise) | 21 | | | | |

VR Environmental scores were tested for normality (Table 34). The "Look" score was marginally outside what would be considered symmetrical (Skewness -.525) and the "Touch" (Skewness -.345) and "Place" (Skewness .481) scores were within what would be considered symmetrical i.e., normally distributed. The "Look" score was not adjusted.

Table 34. VR Env. Test for Normality

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| Look Score | 16 | 282 | 1624 | 1019.63 | 436.290 | -.525 | .564 |
| Touch Score | 16 | 83 | 166 | 129.13 | 20.379 | -.345 | .564 |
| Place Score | 16 | 67 | 110 | 82.94 | 13.714 | .481 | .564 |
| Valid N (listwise) | 16 | | | | | | |

When comparing action scores, the 16 VR participants' "look", "touch" and "place" scores, did not show a statistically significant difference for gender (Table 50, Table 53), Age (Table 52), Education (Table 51), or English proficiency (Table 53) (Tables for reference in appendix Section 10. 9). **Summary**: profile had no statistically significant effect on actions scores in the VR environment.

PC Static Environmental scores were tested for normality (Table 34, Table 35). The "Look" score was marginally outside what would be considered symmetrical (Skewness -.574) and the "Touch" (Skewness -.463) and "Place" (Skewness .838) scores were within what would be considered symmetrical i.e., normally distributed. The "Look" score was not adjusted.

Table 35. PC Static Env. Test for Normality

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| Look Score | 21 | -476.00 | 293.00 | -214.6190 | 184.69961 | .574 | .501 |
| Touch Score | 21 | 40.00 | 71.00 | 56.6190 | 6.86641 | -.463 | .501 |
| Place Score | 21 | 71.00 | 155.00 | 106.3333 | 20.33306 | .838 | .501 |
| Valid N (listwise) | 21 | | | | | | |

When comparing action scores, the 21 PC Static participants' "look", "touch" and "place" scores did not show a statistically significant difference for gender (Table 56,), Age (Table 54) Education (Table 57), or English proficiency (Table 61) (Tables for reference in appendix Section 9. 9). **Summary**: profile had no statistically significant effect on actions scores in the Static PC environment.

**Discussion**: from the measurements, it appears that the actions inside each environment were consistent regardless of age, education level, gender or role. The time spent solving the challenges was longer in the VR environment and this is possibly to be expected as the VR environment did not allow the participants to stand in the centre of the island and complete the task as the PC environment did. Future research may show a link between the amount of time spent in the environment and the improvement in performance as the VR adaptive environment did show the strongest effect on post-test results.

## 7.9 Inferential Question Analysis All Environments

Questions in the pre and post-tests were structured so that each sense of "over" had three questions relating to it (Figure 75). Within the game, these senses had physical actions (mechanics) (Table 3) which needed to be performed to complete the challenge on an island. This analysis section explores the relationship between the sense scores in the tests and the grouping of those senses by the mechanic in the challenges. Sense scores are treated as scale for parametric tests. There are only three questions per sense with a minimum score of 0 and a maximum score of 3.

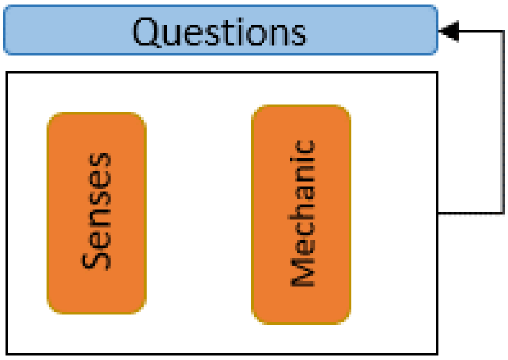


Figure 75. Analysis of Environment: Sense

Table 1. Research Questions

| | |
|---|---|
| **Research Question 1** | Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of 'over'? |
| **Research Question 2** | Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile? |
| **Research Question 3** | Did performance vary by sense or mechanic? |
| **Research Question 4** | Did profile differences between participants' factor in predicting performance in the VR or PC game? |

Across all conditions, the sense scores in pre and post-test results for all 56 participants (Table 36 all conditions) show a statistically significant difference for "cover" ($p\ 0.001 < 0.05$), "temporal" ($p\ 0.032 < 0.05$) and "excess2: more than" ($p\ 0.016 < 0.05$) senses.

Table 36. Session Comparison of Sense Scores

**Paired Samples Test**

| | | Paired Differences | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval of the Difference | | | |
| | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | Sig. (2-tailed) |
| Pair 1 | Proto Session 1 vs 2 | .150 | .864 | .137 | -.126 | .426 | 1.098 | .279 |
| Pair 2 | Excess1 Session 1 vs 2 | -.150 | .802 | .127 | -.407 | .107 | -1.183 | .244 |
| Pair 3 | Other Side Session 1 vs 2 | -.100 | .744 | .118 | -.338 | .138 | -.850 | .401 |
| Pair 4 | Complete Session 1 vs 2 | -.075 | .526 | .083 | -.243 | .093 | -.902 | .372 |
| Pair 5 | Transfer Session 1 vs 2 | .050 | .597 | .094 | -.141 | .241 | .530 | .599 |
| Pair 6 | Control Session 1 vs 2 | -.075 | .829 | .131 | -.340 | .190 | -.572 | .570 |
| Pair 7 | Temporal Session 1 vs 2 | -.150 | .427 | .067 | -.286 | -.014 | -2.223 | .032 |
| Pair 8 | Cover Session 1 vs 2 | -.425 | .747 | .118 | -.664 | -.186 | -3.597 | .001 |
| Pair 9 | Focus Session 1 vs 2 | -.200 | .823 | .130 | -.463 | .063 | -1.537 | .132 |
| Pair 10 | Preference Session 1 vs 2 | .025 | .357 | .056 | -.089 | .139 | .443 | .660 |
| Pair 11 | Reflexive Session 1 vs 2 | -.025 | .480 | .076 | -.178 | .128 | -.330 | .743 |
| Pair 12 | Repeat Session 1 vs 2 | .100 | .379 | .060 | -.021 | .221 | 1.669 | .103 |
| Pair 13 | Excess2 Session 1 vs 2 | -.250 | .630 | .100 | -.452 | -.048 | -2.508 | .016 |

Where session 1 is the pre-test and session 2 is the post-test the “Cover” mean increased from m=1.71 to m=2.07 (Table 37, Figure 76), “Excess2” mean increased from m=1.71 to m=2.07 (Table 38, Figure 77), and the “Temporal” mean increased from m=1.71 to m=2.07 (Table 39).

Table 37. Sense Cover Mean Increase

**Descriptive Statistics**

| Session | | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| 1.00 | Cover | 56 | .00 | 3.00 | 1.7143 | .92862 |
| | Valid N (listwise) | 56 | | | | |
| 2.00 | Cover | 56 | .00 | 3.00 | 2.0714 | .82808 |
| | Valid N (listwise) | 56 | | | | |

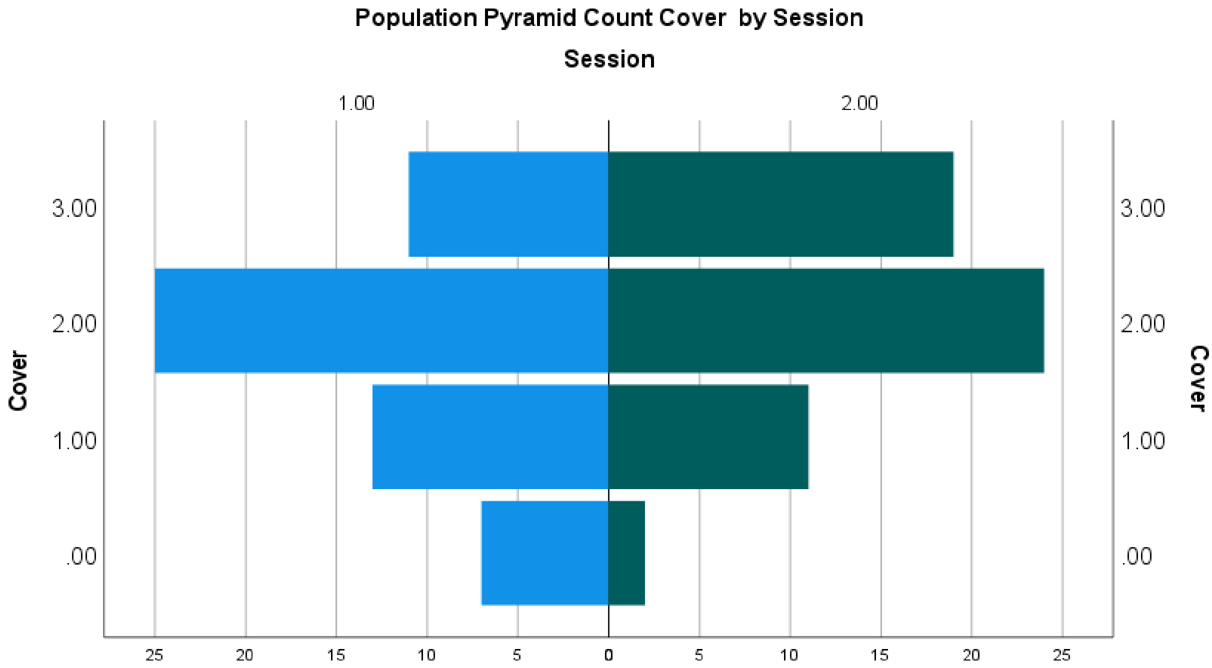


Figure 76. Cover Score Frequency

Table 38. Sense Excess Mean Increase

**Descriptive Statistics**

| Session | | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| 1.00 | Excess2 | 56 | .00 | 3.00 | 2.5536 | .71146 |
| | Valid N (listwise) | 56 | | | | |
| 2.00 | Excess2 | 56 | .00 | 3.00 | 2.7679 | .63220 |
| | Valid N (listwise) | 56 | | | | |

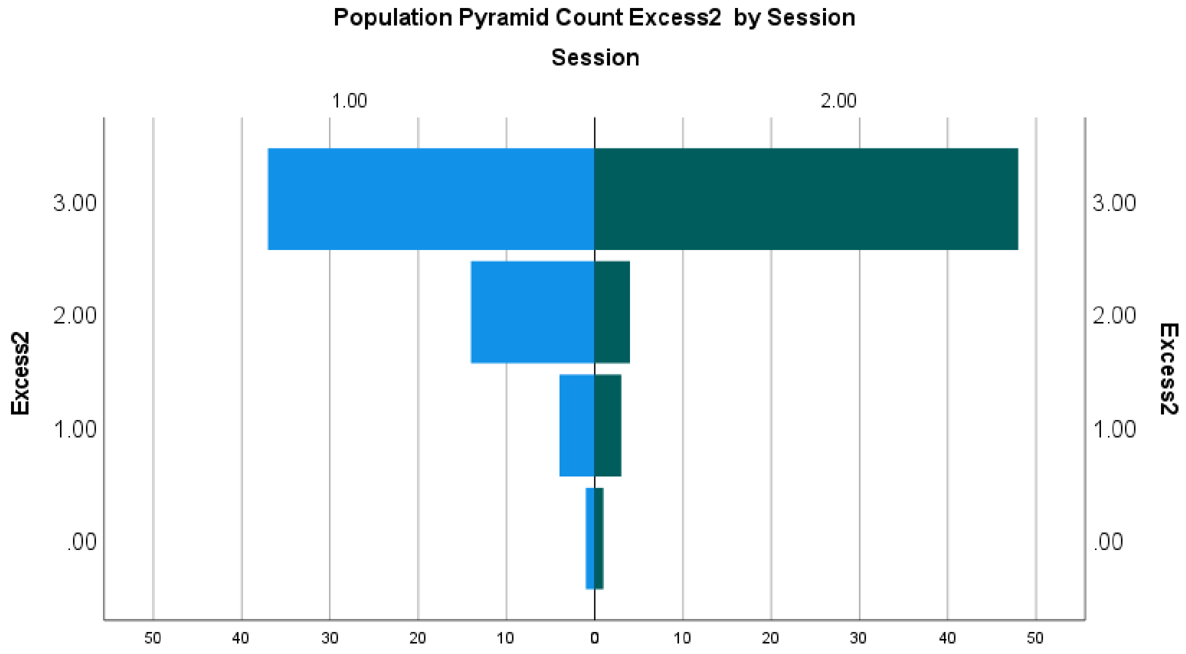


Figure 77. Excess Score Frequency

Table 39. Sense Temporal Mean Increase

**Descriptive Statistics**

| Session | | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| 1.00 | Temporal | 56 | .00 | 3.00 | 2.6607 | .64036 |
| | Valid N (listwise) | 56 | | | | |
| 2.00 | Temporal | 56 | 2.00 | 3.00 | 2.8393 | .37059 |
| | Valid N (listwise) | 56 | | | | |

When comparing all conditions for all 56 participants, the sense scores in pre and post-test results in adaptive and Static environments (Table 40) show a statistically significant difference for the senses “cover” static (p 0.001 < 0.05) compared to adaptive (p 0.083 < 0.05), “temporal” static (p 0.160 > 0.05) compared to adaptive (p 0.020 < 0.05), and “excess2: more than” Static (p 0.765 > 0.05) compared to adaptive (p 0.004 < 0.05) senses (Zeros excluded).

The effect sizes (Section 9. 11, Table 62) for “cover” static were medium ( -0.545) compared to adaptive low (-.210), “temporal” non-low (-.221), compared to adaptive low (-.285), and “excess2-more than” Static low (-.068), compared to adaptive low (-.358), senses. **Summary**: these effect sizes were low and likely to be insignificant.

Table 40. Comparison of Sense Scores Adaptive

**Paired Samples Test**

| Adaptive | | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference Lower | Upper | | | |
| N | Pair 1 | Proto Session 1 vs 2 | .02381 | .41249 | .06365 | -.10473 | .15235 | .374 | 41 | .710 |
| | Pair 2 | Excess Session 1 vs 2 | -.11905 | .59274 | .09146 | -.30376 | .06566 | -1.302 | 41 | .200 |
| | Pair 3 | Other Side Session 1 vs 2 | -.07143 | .40682 | .06277 | -.19820 | .05535 | -1.138 | 41 | .262 |
| | Pair 4 | Completion Session 1 vs 2 | -.04762 | .21554 | .03326 | -.11479 | .01955 | -1.432 | 41 | .160 |
| | Pair 5 | Transfer Session 1 vs 2 | -.07143 | .34165 | .05272 | -.17789 | .03504 | -1.355 | 41 | .183 |
| | Pair 6 | Control Session 1 vs 2 | -.04762 | .58236 | .08986 | -.22909 | .13386 | -.530 | 41 | .599 |
| | Pair 7 | Temporal Session 1 vs 2 | -.04762 | .21554 | .03326 | -.11479 | .01955 | -1.432 | 41 | .160 |
| | Pair 8 | Cover Session 1 vs 2 | -.33333 | .61154 | .09436 | -.52390 | -.14276 | -3.532 | 41 | .001 |
| | Pair 9 | Focus Session 1 vs 2 | -.07143 | .40682 | .06277 | -.19820 | .05535 | -1.138 | 41 | .262 |
| | Pair 11 | Reflexive Session 1 vs 2 | -.02381 | .26943 | .04157 | -.10777 | .06015 | -.573 | 41 | .570 |
| | Pair 13 | Excess2 Session 1 vs 2 | -.02381 | .34838 | .05376 | -.13237 | .08475 | -.443 | 41 | .660 |
| Y | Pair 1 | Proto Session 1 vs 2 | .04286 | .66889 | .07995 | -.11663 | .20235 | .536 | 69 | .594 |
| | Pair 2 | Excess Session 1 vs 2 | -.01429 | .39902 | .04769 | -.10943 | .08086 | -.300 | 69 | .765 |
| | Pair 3 | Other Side Session 1 vs 2 | .02857 | .58907 | .07041 | -.11189 | .16903 | .406 | 69 | .686 |
| | Pair 4 | Completion Session 1 vs 2 | -.07143 | .46067 | .05506 | -.18127 | .03841 | -1.297 | 69 | .199 |
| | Pair 5 | Transfer Session 1 vs 2 | -.05714 | .53530 | .06398 | -.18478 | .07049 | -.893 | 69 | .375 |
| | Pair 6 | Control Session 1 vs 2 | -.05714 | .56172 | .06714 | -.19108 | .07679 | -.851 | 69 | .398 |
| | Pair 7 | Temporal Session 1 vs 2 | -.11429 | .40083 | .04791 | -.20986 | -.01871 | -2.386 | 69 | .020 |
| | Pair 8 | Cover Session 1 vs 2 | -.08571 | .40799 | .04876 | -.18300 | .01157 | -1.758 | 69 | .083 |
| | Pair 9 | Focus Session 1 vs 2 | -.12857 | .70034 | .08371 | -.29556 | .03842 | -1.536 | 69 | .129 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pair 11 | Reflexive Session 1 vs 2 | -.01429 | .43382 | .05185 | -.11773 | .08915 | -.276 | 69 | .784 |
| Pair 13 | Excess2 Session 1 vs 2 | -.15714 | .43857 | .05242 | -.26172 | -.05257 | -2.998 | 69 | .004 |
| Pair 10 | Preference Session 1 vs 2 | .01429 | .26881 | .03213 | -.04981 | .07838 | .445 | 69 | .658 |
| Pair 12 | Repetition Session 1 vs 2 | .05714 | .28921 | .03457 | -.01182 | .12610 | 1.653 | 69 | .103 |

Mechanics are described in section 4. 7 and are not evenly distributed among the senses in the game. “Exploring” and “Sorting” relate to the actions of 1 sense each, “Ordering” relates to 2 senses, “Selecting” relates to 3 senses and “Matching” relates to 6 senses. The following analysis is of the participants' scores (total of successful answers) for the senses grouped by the mechanic.

In the VR adaptive environments mechanic scores (mechanic score is the total of the sense scores which are grouped under the mechanic, section 4. 7) were tested for statistically significant changes. “Sorting” (Table 41, Table 42shows a statistically significant difference between test scores (p 0.005 < 0.05). The Cohen’s D point estimate ( Table 43) effect size, suggests this had a medium effect (size is greater than 5).

Table 41. VR Mechanic Paired T-Test

**Paired Samples Test[a]**

| | | Paired Differences | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval of the Difference | | | | |
| | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Pair 1 | Sorting1 - Sorting2 | -.28125 | .52267 | .09240 | -.46969 | -.09281 | -3.044 | 31 | .005 |
| Pair 2 | Exploring1 - Exploring2 | -.12500 | .65991 | .11666 | -.36292 | .11292 | -1.072 | 31 | .292 |
| Pair 3 | Ordering1 - Ordering2 | -.09375 | .29614 | .05235 | -.20052 | .01302 | -1.791 | 31 | .083 |
| Pair 4 | Selecting1 - Selecting2 | -.18750 | .53506 | .09459 | -.38041 | .00541 | -1.982 | 31 | .056 |
| Pair 5 | Matching1 - Matching2 | -.21875 | .79248 | .14009 | -.50447 | .06697 | -1.561 | 31 | .129 |

a. PC = No, Adaptive = Yes

Table 42. VR Mechanic Effect Size

**Paired Samples Effect Sizes[a]**

| | | | Standardizer[b] | Point Estimate | 95% Confidence Interval Lower | 95% Confidence Interval Upper |
|---|---|---|---|---|---|---|
| Pair 1 | Sorting1 - Sorting2 | Cohen's d | .52267 | -.538 | -.906 | -.163 |
| | | Hedges' correction | .52910 | -.532 | -.895 | -.161 |
| Pair 2 | Exploring1 - Exploring2 | Cohen's d | .65991 | -.189 | -.538 | .162 |
| | | Hedges' correction | .66803 | -.187 | -.531 | .160 |
| Pair 3 | Ordering1 - Ordering2 | Cohen's d | .29614 | -.317 | -.669 | .041 |
| | | Hedges' correction | .29979 | -.313 | -.661 | .041 |
| Pair 4 | Selecting1 - Selecting2 | Cohen's d | .53506 | -.350 | -.705 | .009 |
| | | Hedges' correction | .54164 | -.346 | -.696 | .009 |
| Pair 5 | Matching1 - Matching2 | Cohen's d | .79248 | -.276 | -.627 | .079 |
| | | Hedges' correction | .80223 | -.273 | -.619 | .078 |

a. PC = No, Adaptive = Yes

b. The denominator used in estimating the effect sizes.

Cohen's d uses the sample standard deviation of the mean difference.

Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

In the PC static environment5 mechanic scores were tested for statistically significant changes. “Ordering” (Table 43, Table 44) shows a statistically significant difference between test scores (p 0.001 < 0.05). Cohen’s D point estimate (Table 44, effect size) suggests this had a medium effect (size is greater than 5). In the PC adaptive environment5 mechanic scores were tested for statistically significant changes. None showed a statistically significant difference between test scores (Table 45)

Table 43. PC Static Mechanic Paired T-Test

**Paired Samples Test**[a]

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference Lower | Upper | | | |
| Pair 1 | Sorting1 - Sorting2 | -.07143 | .34165 | .05272 | -.17789 | .03504 | -1.355 | 41 | .183 |
| Pair 2 | Exploring1 - Exploring2 | -.07143 | .40682 | .06277 | -.19820 | .05535 | -1.138 | 41 | .262 |
| Pair 3 | Ordering1 - Ordering2 | -.33333 | .61154 | .09436 | -.52390 | -.14276 | -3.532 | 41 | .001 |
| Pair 4 | Selecting1 - Selecting2 | -.02381 | .46790 | .07220 | -.16962 | .12200 | -.330 | 41 | .743 |
| Pair 5 | Matching1 - Matching2 | -.33333 | 1.1617 | .17926 | -.69535 | .02868 | -1.860 | 41 | .070 |

a. PC = Yes, Adaptive = No

Table 44. PC Static Mechanic Effect Sizes

**Paired Samples Effect Sizes**[a]

| | | | Standardizer[b] | Point Estimate | 95% Confidence Interval Lower | Upper |
|---|---|---|---|---|---|---|
| Pair 1 | Sorting1 - Sorting2 | Cohen's d | .34165 | -.209 | -.514 | .098 |
| | | Hedges' correction | .34482 | -.207 | -.509 | .097 |
| Pair 2 | Exploring1 - Exploring2 | Cohen's d | .40682 | -.176 | -.479 | .130 |
| | | Hedges' correction | .41059 | -.174 | -.475 | .129 |
| Pair 3 | Ordering1 - Ordering2 | Cohen's d | .61154 | -.545 | -.867 | -.218 |
| | | Hedges' correction | .61721 | -.540 | -.859 | -.216 |
| Pair 4 | Selecting1 - Selecting2 | Cohen's d | .46790 | -.051 | -.353 | .252 |
| | | Hedges' correction | .47224 | -.050 | -.350 | .250 |
| Pair 5 | Matching1 - Matching2 | Cohen's d | 1.16172 | -.287 | -.594 | .023 |
| | | Hedges' correction | 1.17248 | -.284 | -.589 | .023 |

a. PC = Yes, Adaptive = No

b. The denominator used in estimating the effect sizes.

Cohen's d uses the sample standard deviation of the mean difference.

Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

Table 45. PC Adaptive Mechanic Paired T-Test

**Paired Samples Test**[a]

| | | Paired Differences | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 95% Confidence Interval of the Difference | | | | |
| | | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | Sig. (2-tailed) |
| Pair 1 | Sorting1 - Sorting2 | .13158 | .47483 | .07703 | -.02449 | .28765 | 1.708 | 37 | .096 |
| Pair 2 | Exploring1 - Exploring2 | -.13158 | .74148 | .12028 | -.37530 | .11214 | -1.094 | 37 | .281 |
| Pair 3 | Ordering1 - Ordering2 | .02632 | .63616 | .10320 | -.18278 | .23541 | .255 | 37 | .800 |
| Pair 4 | Selecting1 - Selecting2 | .13158 | 1.2557 | .20370 | -.28116 | .54432 | .646 | 37 | .522 |
| Pair 5 | Matching1 - Matching2 | -.42105 | 1.4071 | .22827 | -.88357 | .04147 | -1.845 | 37 | .073 |

a. PC = Yes, Adaptive = Yes

**Summary**: in the VR environment "sorting" which was represented in a single sense, showed a statistically significant difference in test scores. In the PC static environment "ordering" which was represented in two senses, showed a statistically significant difference in test scores. Both with a medium effect on scores.

**Discussion**: The sorting challenge in VR proved to be one of the more difficult. Of the 16 participants 6 verbally requested clarification on the challenge. It may be that the increased complexity resulted in increased attention and that having to consider actions resulted in a more memorable experience. The converse may also be true. The simplicity needed for a game and challenge which could be completed by a wide range of people, with a wide range of computer skills, as described in design methods chapter 4, may have reduced the cognitive requirements to such a simplistic level that the challenges were almost automatic for some participants. In the PC static environment, the "ordering" sense was represented by the "cover" challenge and the "repeat" challenge. These senses do not appear to be related and it is not immediately apparent why the mechanic of "ordering" would have any significance. It may be useful for future research to understand how ordering and other mechanics influence learning outcomes.

# 8 Discussion, Conclusion, Contribution, and Future Research

## 8.1 Discussion

This research used two main platforms. The VR platform and the PC version which was essentially a response to COVID restrictions. The teaching game was created for VR and adapted for the PC environment when it became clear that the virtual reality research would be delayed due to COVID-19. The human-computer interaction (HCI) used with a PC is very different from that experienced in virtual reality [46] and initially, the VR interactions were too complex to copy directly to the PC as they required participants to navigate with too many keystrokes. Pilot tests showed that interaction received a better reaction from the players when it was essentially a "point and click" function. The result of this "point and click" method was that the participants did not need to engage with the environment in an overly computer-literate/dexterous way. This is in line with the design consideration in chapter 4.4 of reducing complexity outside of the challenge. Instead, players were able to review the scene and select and drop items from tables onto the target boxes without having to engage the avatar with the environment. Given that the adaptive elements of the environment were intended to be subtle, it is perhaps not surprising that in a PC environment where engagement was less immersive, the effect of such subtle changes was negligible. This may also be an effect of perception proximity. In virtual reality, a participant would look at a bird on a table and the bird would turn to look directly at them. In the PC environment the participant surveys the screen and must discern whether, for example, the bird is looking at the avatar. It could be said that a key learning point from this research is that an adaptive environment intended to influence behaviour, may require as a prerequisite an immersive environment such as virtual reality. The fact that the only strong effect seen on learning outcomes was measured in the virtual reality environment which used adaptive changes, may support this theory. Situational effects such as changes in the wind and light functions have distinctly different effects in virtual reality. In VR these changes immerse the participant in the environment, whereas on a PC screen the participant is a spectator of the changes occurring on the screen. The design framework is intended to be subtle, and the changes are not intended to enter the player's consciousness directly. Essentially this is the difference between seeing the environment change and feeling the environment changing.

Generally, the test results from both PC game conditions were higher than the test results in the virtual reality version. This was true for both the pre-test and the post-test and may be due to the remote nature of the experimental conditions. Remote testing is very different to classroom-based testing; however, they need not necessarily be less effective [146]. Even though the test themselves were the same, anecdotally remote tests were the source of discussion and as a result, the scores could represent co-constructed conclusions. It may be interesting to compare language-based online tests where co-construction was an experimental condition.

In this research, participants were only able to experience the environments once. This limited the "learn, practice, master" loop, and given that the challenges were based on language concepts, the participants may not have had enough experience with the game to change behaviour. In approximately 33% of cases, data received from those completing the PC challenge remotely showed that the game had been restarted at least once. Does this pose the question; were the remote participants playing the game several times? If they were, this could point to either; the novelty of the game; a desire to learn the preposition; or simply technology failure. Either way, it is unlikely that repeated play would account for the higher scores in the PC group. If repeating gameplay was the key factor, only the post-test score averages would have been higher.

The lower action scores in the PC game are unlikely to be attributable to the difference in mechanics as PC players did not need to move to the centre of the island or towards the tables. The time spent inside the VR game was longer (5 minutes) than the PC game and a future study might include supervised use of the PC game to see whether the difference in time spent was due to the actual game or the supervision of it.

## 8.2 Conclusion

This thesis considers the potential of adaptive environments for the enhancement of learning. It uses the concept of an English preposition as the lens through which to explore the effects of adaptive environmental changes on participants learning outcomes. This exploration was conducted through the use of a serious game designed and implemented on two separate platforms. A PC platform which participants used remotely on their PCs and a virtual reality platform was used with the supervision of the researcher. The research hypothesis suggested that if the environment reacted in positive and negative ways to the correct and incorrect actions of the participants, these reactions would act as a form of scaffolding for the learning process. The data for analysis was collected from:

- pregame and post-game tests to measure differences in understanding
- actions were taken by the participants within the game
- the amount of time taken by participants to complete the game on the different platforms
- questions organised based on the meanings that they represent
- questions with the mechanics used within the game considered

The analysis was focused upon 4 research questions:

1) Did the use of either the VR or PC game help L2 English users improve their knowledge of the various meanings of ‘over’?

The use of all environments resulted in test score improvements. However, the change in test scores in the PC adaptive environment was not statistically significant. While the change in PC static environment test scores was statistically significant, in that it had what would be considered to have had a medium effect on the change. The improvement in test scores after the use of the VR environment was statistically significant and its effect was considered strong, therefore the VR environment could be considered the more successful of the conditions in improving learning outcomes. Nevertheless, the data collected does not prove the hypothesis that an adaptive framework would improve learning outcomes.

2) Did interactions in the VR or PC game differ by task and did those differences correlate to differences in performance or profile?

In the VR environment the actions of “look”, “touch” and “place” did not show any statistically significant difference when compared to age, gender, education level, or English proficiency. This was also true in the PC static environment.

3) Did performance vary by sense or mechanic?

The test scores for the senses “Cover”, “Excess” (more than) and the “temporal” sense, showed statistically significant improvements suggesting that understanding of these senses had been increased. The effect sizes for “Excess” and the temporal senses we're only seen in the adaptive environments and would be considered low and possibly marginal. The effect size for “Cover” would be considered medium.

In the VR environment, the sorting mechanic was the only mechanic that showed a significant difference between test scores, and this mechanic had an effect size which would be considered medium. However, it is worth noting that the sorting mechanic only has one sense attributed to it within the games and this may have skewed the results.

In the PC static environment, the mechanic “ordering” showed a statistically significant difference between test scores and the effect size was shown to be medium. In the PC adaptive environment, no mechanics showed statistically significant changes in test scores.

4) Did profile differences between participants factor in predicting performance in the VR or PC game?

Test scores across all platforms were statistically unaffected by profile items such as age, English proficiency, level of education, and gender. While the amount of time taken to complete each game cannot be compared across platforms due to their very different experimental conditions, the PC platform with an adaptive environment had a mean time to complete of almost double the mean time to complete in the Static PC platform.

## 8.3 Contribution

- To address the need for quantitative analysis of VR Language teaching systems a detailed definition of an adaptive framework focused on proximal and environmental changes, based on the actions of the participant was created. This framework can be used as the basis for the development of interactive serious games aimed at teaching language concepts.
- As the design of VR teaching systems based on cognitive learning theory is a new research area this research identifies specific design principles for serious language games with variation in platforms namely:
  - avoid extraneous text, and let the game design guide
  - use the theme to reduce complexity outside of the immediate challenge
  - content fidelity, only include relevant challenges in the game
  - limit options to maintain forward motion
  - avoid punishing any action
- The research details a direct comparison of PC and VR language teaching and identifies the design principles for a serious game used to teach English prepositions through PC and Oculus platforms not previously available in the literature. Highlighting that researchers should be aware of the game mechanics used for tasks, and evenly distribute them so that measurable effects can be analysed.
- A description of the effect of different platforms when implementing adaptive environments. i.e., researchers may not find environmental changes useful on the PC platform for influencing learning outcomes and conversely researchers may find environmental changes in VR very useful for influencing learning outcomes. This contributes to the rigorous design approach advocated by Grgurovic, Chapelle et al in their meta-analysis of CALL-supported Language learning [147].
- An analysis of the effect of homogeneity within participant groups. Researchers should be aware of how dominant the selection criteria can be in language research. For example, in this research selecting L2 participants attending an English university essentially negated any influence from other profile elements such as gender, English proficiency, level of education or age.

- An indication of a potential co-constructed learning approach for L2 learners. In this research, this was a side effect of the remote research method, however, it provides quantitative data on results from PC and VR platforms not currently available in the literature for cognitive linguistics. Future researchers may use these indicators to account for differences in remote versus in-person language research [26].
- This research contributes to a relatively small number of quantitative studies focused on L2 language learning in games [148]
- The design of L2 pedagogical materials such as Cognitive Linguistic focused questionnaires for measurement and enacted and embodied tasks implemented in-game challenges. These were underpinned by theoretically informed principles from Cognitive Linguistics, psychology, Education, and game design [149].
- The research synthesises the affordances of VR and the theories of enaction and cognitive learning creating a novel teaching and learning approach aimed at maximising the affordances of the technology used, rather than reproducing existing teaching materials, the need for which is described by Lan [150] and follows the model of convergence suggested by Reinders et al [151] where technology and learner autonomy domains come together.
- A comparison of two platforms, PC and VR, in L2 teaching, as opposed to comparing classroom teaching to computer-based teaching as seen in studies such as Ngu et al [49].
- This research is an interdisciplinary (computer-science + Second Language Acquisition (SLA)) quantitative study, rather than a wholly ethnographic study, and therefore provides data to support future deductive research (generalising from specifics) rather than the more common SLA inductive research (assuming specifics from generalities) such as interpreting research results through the lens of culture and customs [161].

## 8.4 Notes for Games Designers

When designing for educational purposes reducing complexity and ensuring that flow is context driven i.e., challenges are relevant to the subject matter appear to support the learning process. While this research did not test the difference between contextual and irrelevant challenges in educational games, the discourse with players was entirely focused on the subject matter and no player expressed doubt over the purpose or relevance of a challenge. The lack of “punishment” appeared to support game flow further enhancing the focus on the subject matter, as did the attention to forward motion in the game. The differences in results between VR and PC games indicate that the point of view (POV) of the player may be a determining factor in the level of influence the designer can have on the outcome. PC POV is predominantly outside looking in and may be better suited to collaborative challenges where the collaborators can share the same experience and discuss, co-construct and evolve their understanding using the PC as an agent in the understanding process. The VR experience is personal in that a player cannot enact a solution for someone else. It could be that some learning processes benefit from a purely personal experience because the learning needs are themselves personal. There may be a measurable difference between basic functional learning such as language where the individual has a specific profile of understanding based on their specific experience, and higher concept understanding such as solving engineering problems where a group can come together and benefit from synergy.

## 8.5 Notes for Educators

Accepting that there will always be limitations on access to educational games using VR technology, this research may help educators argue for the resources needed to implement VR in the classroom. It also provides quantitative data for those teaching through the cognitive linguistic method as VR immersion in a language challenge with an adaptive environment enables us to measure the method's relevance as a teaching tool. This research also provides quantitative data demonstrating the use of computer science as a tool for validating learning theory. The method used is not limited to prepositions and the design framework may be used for a range of teaching materials.

One of the main advantages of VR teaching is its reach and scalability. When considering the return on investment for such a system it should be noted that this method is highly scalable and well suited to remote teaching as once installed the user is autonomous. This also means that the lecturers could benefit from an extended span of control. The level of immersion in a correctly designed VR teaching environment also counters some of the disadvantages of remote learning as it supports active learning strategies [152, p. 7] and allows students to control the pace of their learning.

## 8.6 Limitations

Teaching environments which require the participants to become experts in a single learning session need to be extremely straightforward. This research only allows the participant four attempts at understanding the concept of a preposition before they are forced to progress to the next concept. This presents limitations. The game does not consider the magnitude and frequency of reinforcement required by each participant to properly understand the concept.

The mechanics used in the serious game did not have a similar number of senses associated with them. Consequently, when trying to compare the effect of a specific mechanic on a learning outcome the results were inconsistent. Ideally a single mechanic i.e., "sorting" would be used for an entire game, and that mechanic would be replaced, and the research repeated to create a new distinct research condition.

While the method of testing was consistent across all platforms i.e., the same online questionnaire was presented to all participants, the online tests completed in the PC environments were remote and therefore were not supervised. As a result, the PC tests may not have been completed under the same experimental conditions that would have been observed with the researcher present. PC test scores were on average higher than the scores completed by the participants in the VR setting, and this may represent co-constructed results (i.e., the result of discussion and consensus of more than one person).

The implementation of the day-night cycle timer in the 13th sense introduced an anomaly in environmental actions. This was because the participant had to wait for the night cycle to begin before they could complete the task, and while they waited, they invariably "looked", "touched" or even "placed" items essentially to pass the time.

Participation in the remote version of the research may have had a self-selecting criterion as to participate the participant was required to download and install the game onto their PC. Therefore, they would require a level of technical knowledge, and this could have created a self-selecting bias in the group. University language students and their friends were invited to participate in the study via email. This email stated the criteria “second language English speaker” and where participants were not directly from the university there was a follow-up conversation to ensure that they were students or graduates of an English-speaking university. This resulted in a self-selecting group. Those confident enough to join the study and interested in improving their understanding of an English preposition.

The lack of a control study for the VR group represents an important limitation. The inference could more easily be drawn from a VR control group, and this remains a goal for future research.

## 8.7 Future Work

A larger number of participants using both the adaptive and Static VR games would enable direct analysis of the adaptive and Static effects on learning outcomes in a VR environment. This research indicates that subtle changes to both situational awareness and proximal objects on a PC platform, or at least on a small screen may not be directly useful in influencing learning outcomes for language concepts.

It may be advantageous to use both the PC and VR environments as teaching tools many times over several weeks. In conjunction with a comparative classroom syllabus, this could be an interesting future project. The VR game was noticeably tiring to many of the participants which may suggest a cognitive load issue or that their engagement was extremely heightened. The effect of increasing sensory input whilst trying to teach a concept, or the effect of increased levels of environmental engagement on learning outcomes, could be studied to adjust and optimise learning environments. Anecdotally participants in the VR research appeared to notice the situational awareness changes more than they noticed the changes in attention-seeking items such as the birds turning to face them. This could be an effect of proximity, or it could mean that there are varying degrees of subtlety which are directly correlated with attention given to the environment. For example, enhanced situational awareness could result in greater importance being given to noticing subtle changes in external environments as opposed to paying attention to proximal changes. From the experience of this research, it would seem that while it is possible to create single one-off experiences to test learning outcomes in language, and these do appear to have an effect, a longer research period with a larger number of sessions may be more appropriate. While it was not part of this research, it is suspected that co-constructed learning took place when the challenge was completed remotely due to the higher test scores achieved. Further research into the effect of co-constructed learning in a testing environment on individual learning may be useful.

Due to the circumstances in which the research was conducted the participants tended to be drawn from a restricted sample of learners and while it is perhaps not surprising that younger participants appeared to do better in VR, these were all educated participants with proficient English skills, it may be useful to see if the effect of VR was increased with different population types. For example, participants with a rudimentary understanding of English may benefit more from symbolic representations of the concepts.

While augmented reality cannot change situational awareness because it is viewed through the small screen of a mobile phone, a combination of external sensors controlled by the mobile phone and an augmented reality challenge may prove very effective. In such a situation the research would not rely on the participant's immersion to learn more effectively but instead, the changes in situational awareness would be real. The mobile phone itself could provide feedback through vibration, sound, and an element of external light using the flash mechanism, as well as the image displayed on the screen. Where such all-encompassing changes were being controlled by the phone, machine learning agents could certainly be trained to enhance the scaffolding. However, there is currently no research which indicates the effectiveness of such an approach.

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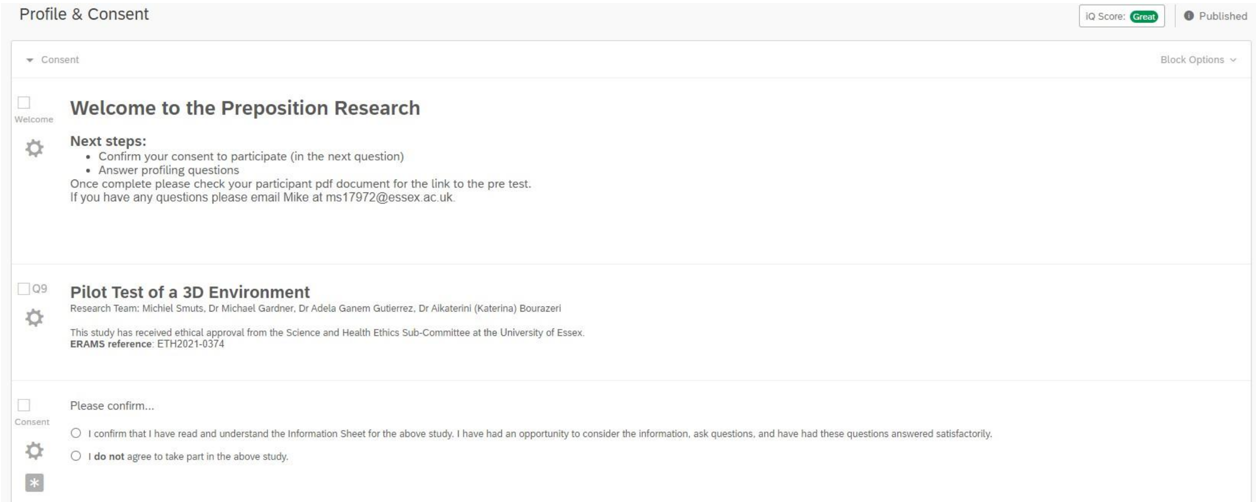
# 9 Appendices

## 9.1 Participant Consent


Profile & Consent

iQ Score: Great

Published

Consent

Block Options

Welcome

**Welcome to the Preposition Research**

**Next steps:**
- Confirm your consent to participate (in the next question)
- Answer profiling questions

Once complete please check your participant pdf document for the link to the pre test.
If you have any questions please email Mike at ms17972@essex.ac.uk.

Q9

**Pilot Test of a 3D Environment**

Research Team: Michiel Smuts, Dr Michael Gardner, Dr Adela Ganem Gutierrez, Dr Aikaterini (Katerina) Bourazeri

This study has received ethical approval from the Science and Health Ethics Sub-Committee at the University of Essex.
**ERAMS reference**: ETH2021-0374

Consent

Please confirm...

○ I confirm that I have read and understand the Information Sheet for the above study. I have had an opportunity to consider the information, ask questions, and have had these questions answered satisfactorily.

○ I **do not** agree to take part in the above study.

## 9.2 Participant Profile

| Question | Options |
|---|---|
| Please indicate your gender | ○ Male (1)<br>○ Female (2)<br>○ Non-binary (3)<br>○ Other (4)<br>○ Rather not say (5) |

| | |
|---|---|
| Please indicate your age range | ◯ Less than 18 (1)<br>◯ 18-24 (2)<br>◯ 25-34 (3)<br>◯ 35-44 (4)<br>◯ 45-54 (5)<br>◯ 55 and over (6)<br>◯ Rather not say (7) |
| Please indicate your role | ◯ Under-Graduate Student (1)<br>◯ Post-Graduate Student (2)<br>◯ Other (3) |
| Proficiency in English | ◯ New to English (1)<br>◯ Early Acquisition (2)<br>◯ Developing Competence (3)<br>◯ Competent (4)<br>◯ Fluent (5) |

## 9.3 Pre and Post-test Questions

| Test Question | Sense | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|---|
| The picture is over the mantel. | Proto | on the other side of… | above… | over and beyond… | covers… |
| The cloud was over the field. | Proto | on the other side of… | above… | over and beyond… | covers… |
| The bee hovered over the flower. | Proto | on the other side of… | above… | over and beyond… | covers… |
| The wind blew the leaves over the house | Excess1 | on the other side of… | above… | over and beyond… | covers… |
| The explosion threw the car over the wall | Excess1 | on the other side of… | above… | over and beyond… | covers… |
| The boy threw the ball over the fence. | Excess1 | on the other side of… | above… | over and beyond… | covers… |
| Stratford is over the river from Birmingham. | Other Side | on the other side of… | above… | over and beyond… | covers… |
| The house is over the hill | Other Side | on the other side of… | above… | over and beyond… | covers… |
| The cat lives over the street. | Other Side | on the other side of… | above… | over and beyond… | covers… |
| The film is over. | Completion | on the other side of… | above… | over and beyond… | completes… |
| The time for discussion is over. | Completion | on the other side of… | above… | over and beyond… | completes… |
| We can go home when the game is over. | Completion | on the other side of… | above… | over and beyond… | completes… |

| | | | | | |
|---|---|---|---|---|---|
| Sally turned the keys to the office over to the janitor. | Transfer | go from one to the other… | above… | over and beyond… | covers… |
| The spectators moved over to the more expensive seats. | Transfer | go from one to the other… | above… | over and beyond… | covers… |
| The thief handed over the stolen items to the police | Transfer | go from one to the other… | above… | over and beyond… | covers… |
| My neighbour always has a positive influence over his pit bull. | Control | focus on… | prefers… | is in control of … | is above… |
| The local council has jurisdiction over parking permits. | Control | focus on… | prefers… | is in control of … | is above… |
| The government should change the regulation over health and safety. | Control | focus on… | prefers… | is in control of … | is above… |
| I was in London over the summer. | Temporal | repeatedly… | temporal | prefers… | more than... |
| The road was fixed overnight. | Temporal | repeatedly… | temporal | prefers… | more than... |
| I will be home over the weekend. | Temporal | repeatedly… | temporal | prefers… | more than... |
| Joan nailed the board over the hole in the wall. | Cover | is above… | focus on… | completes… | covers… |
| The books were over the corners of the table. | Cover | is above… | focus on… | completes… | covers… |
| The cover was over the pool. | Cover | is above… | focus on… | completes… | covers… |
| Frank looked over the train's undercarriage. | Focus | covers… | is above… | focus on… | completes… |
| The committee agonized over the decision. | Focus | covers… | is above… | focus on… | completes… |

| | | | | | |
|---|---|---|---|---|---|
| The general looked over the battlefield. | Focus | covers… | is above… | focus on… | completes… |
| My mother never drives over the speed limit. | Excess2 | Excess | temporal | is above… | on the other side of… |
| The child was over tired and so had difficulty falling asleep. | Excess2 | Excess | temporal | is above… | on the other side of… |
| Your article is over the page limit. | Excess2 | Excess | temporal | is above… | on the other side of… |
| I would choose my car over yours any day. | Preference | Excess | prefers… | focus on… | is above… |
| I am inclined to take coffee over tea. | Preference | Excess | prefers… | focus on… | is above… |
| The children favoured apples over oranges. | Preference | Excess | prefers… | focus on… | is above… |
| The fence fell over. | Falling Down | goes beyond… | to fall on its side… | covers… | prefers… |
| When the wind stopped the car had been blown over. | Falling Down | goes beyond… | to fall on its side… | covers… | prefers… |
| The stack of bricks toppled over. | Falling Down | goes beyond… | to fall on its side… | covers… | prefers… |
| Marty keeps making the same mistake over and over. | Repetition | repeatedly… | prefers… | goes beyond… | more than... |
| The dog circled over and over. | Repetition | repeatedly… | prefers… | goes beyond… | more than... |
| The waves crashed on the rocks over and over again. | Repetition | repeatedly… | prefers… | goes beyond… | more than... |

## 9.4 Participant Information Sheet PC Version


Figure 78. Participant Information Sheet PC

# 9.5 Participant Information Sheet VR Version



**Virtual Reality Teaching Environment**

Researcher: Michiel Smuts
School of Computer Science and Electronic Engineering (CSEE)
Email: ms17972@essex.ac.uk

**Participant Information Sheet**

**What is being researched?**
English prepositions are particularly difficult for foreign language students to learn. This research uses a reconfigurable virtual environment to teach a preposition and measures your performance as well as your actions within the environment. It is hoped that the information collected will provide the basis for a model for Virtual Reality teaching environments.

**Selection of Candidates**
Candidates are selected from university students who attend the Colchester campus.

Any concerns or complaints about the research may be raised with either the researcher or either of their supervisors.

**What will you be asked to do?**

The research will attempt to measure an effect by giving you a short test before the use of the environment and a short test after the use of the environment.

The Research Process

1. Social distancing will be required
2. You will asked to complete an online consent form in the room where the research will take place
3. You will be given the participation information
4. You will then be asked to complete the first online quiz
5. You will then be shown the Virtual Reality environment and asked to complete the game
6. You will then be asked to complete the second online quiz

The entire process is intended to take less than 1 hour 30 minutes.

**The possible advantages and disadvantages of taking part**
You will have the opportunity to experience a Virtual Reality teaching environment and contribute to its improvement. If you find the experience uncomfortable the research will be stopped immediately.
An Amazon voucher worth £10 will be emailed to you upon completion in recognition of your effort.

**Risk Assessment**
It is not anticipated that there will be any risks greater than normally experience in normal life and the use of Virtual Reality headset. The platform is designed to be benign, however, should you wish to end the



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session for whatever reason you will be able to remove the headset at any stage. The researcher will be available to help if required. There will be specific precautions related to COVID, such as cleaning equipment, surfaces and keyboards prior to each research session, social distancing, and the wearing of face masks.

**Data Collection**
Before you participate in the study you will be asked for your consent. This will include your consent to collect the data from your participation and forms the legal basis for the information collection and storage. The data controller is the University of Essex, and the contact is the University Information Assurance Manager (dpo@essex.ac.uk).

We will remove your name from any data we capture to protect your identity. All data we collect in this project will be kept in a password-encrypted external hard-drive. Only researchers on this project will have access to this information and we will not share your information with anyone else. If you decide to withdraw from the study, we will destroy all your identifiable data and the game data you have produced during the research. This study has received ethical approval from the Science and Health Ethics Sub-Committee at the University of Essex (reference number is at the bottom of this page).

**Concerns and Complaints**
If you have any concerns about any aspect of the study or you have a complaint, in the first instance please contact the principal investigator of the project, Michiel Smuts, using the contact details below. If are still concerned, you think your complaint has not been addressed to your satisfaction or you feel that you cannot approach the principal investigator, please contact the departmental Director of Research in the department responsible for this project, Hani Hagras, (e-mail hani@essex.ac.uk). If you are still not satisfied, please contact the University's Research Governance and Planning Manager , Sarah Manning-Press (e-mail sarahm@essex.ac.uk). Please include the ERAMS reference which can be found at the foot of this page.

**Researcher:**
Michiel Smuts
Student
The University of Essex
Colchester, UK
ms17972@essex.ac.uk

**Supervisors:**

**Dr Adela Ganem Gutierrez**
School of Computer Science and Electronic Engineering (CSEE)
The University of Essex
Colchester, UK
aganem@essex.ac.uk

**Dr Aikaterini (Katerina) Bourazeri**
School of Computer Science and Electronic Engineering (CSEE)
The University of Essex
Colchester, UK
a.bourazeri@essex.ac.uk

**ERAMS reference**: ETH2021-1576

Colchester Campus
Wivenhoe Park
Colchester CO4 3SQ
T 01206 873333
www.essex.ac.uk

Figure 79. Participation Sheet VR

## 9.6 Participation Invites


Figure 80. Virtual Reality Invitation

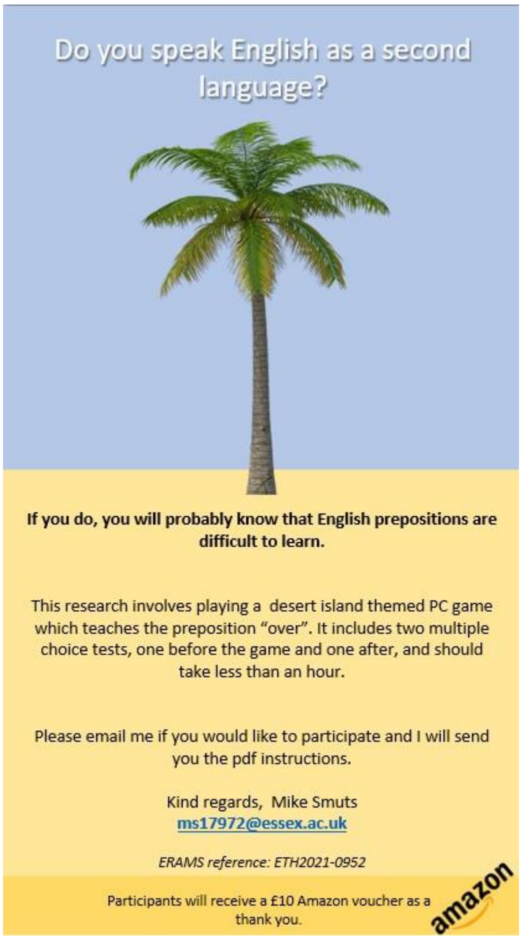


Figure 81. PC Invitation

## 9.7 Environment Skew Test

Table 46. Environment Action Skew Test

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| SumOfLook | 40 | -1407 | 949 | -69.85 | 439.177 | -.680 | .374 |
| SumOfTouch | 40 | 34 | 160 | 63.93 | 27.951 | 1.603 | .374 |
| SumOfPlace | 40 | 47 | 179 | 103.82 | 35.584 | .455 | .374 |
| Valid N (listwise) | 40 | | | | | | |

Table 47. Normalized Environment Action Scores

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| SumOfLook | 40 | -1407 | 949 | -69.85 | 439.177 | -.680 | .374 |
| SumOfPlace | 40 | 47 | 179 | 103.82 | 35.584 | .455 | .374 |
| NormTouch | 40 | 1.53 | 2.20 | 1.7725 | .16525 | .725 | .374 |
| Valid N (listwise) | 40 | | | | | | |

# 9.8 Sense Skew Test

Table 48. VR Questions Grouped by Sense

**Descriptive Statistics**[a]

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| Proto | 32 | 0 | 3 | 2.44 | .801 | -1.392 | .414 |
| Excess1 | 32 | 0 | 0 | .00 | .000 | . | . |
| OtherSide | 32 | 0 | 0 | .00 | .000 | . | . |
| Completion | 32 | 0 | 2 | .50 | .568 | .563 | .414 |
| Transfer | 32 | 0 | 3 | 2.16 | .920 | -.859 | .414 |
| Control | 32 | 0 | 3 | .09 | .530 | 5.657 | .414 |
| Temporal | 32 | 1 | 3 | 2.81 | .471 | -2.610 | .414 |
| Cover | 32 | 1 | 3 | 2.22 | .706 | -.340 | .414 |
| Focus | 32 | 0 | 3 | 2.31 | .859 | -1.000 | .414 |
| Preference | 32 | 2 | 3 | 2.94 | .246 | -3.795 | .414 |
| Reflexive | 32 | 1 | 3 | 2.72 | .523 | -1.721 | .414 |
| Repetition | 32 | 2 | 3 | 2.94 | .246 | -3.795 | .414 |
| Excess2 | 32 | 1 | 3 | 2.81 | .535 | -2.874 | .414 |
| Valid N (listwise) | 32 | | | | | | |

a. PC = No

Table 49. PC Questions Grouped by Sense

**Descriptive Statistics[a]**

| | N | Minimum | Maximum | Mean | Std. Deviation | Skewness | |
|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error |
| Proto | 80 | 0 | 3 | 2.32 | .808 | -.813 | .269 |
| Excess1 | 80 | 0 | 3 | .45 | .727 | 1.494 | .269 |
| OtherSide | 80 | 0 | 3 | 1.83 | 1.178 | -.462 | .269 |
| Completion | 80 | 0 | 3 | 2.34 | 1.124 | -1.417 | .269 |
| Transfer | 80 | 1 | 3 | 2.52 | .711 | -1.173 | .269 |
| Control | 80 | 0 | 3 | 1.71 | .970 | -.582 | .269 |
| Temporal | 80 | 0 | 3 | 2.72 | .551 | -2.378 | .269 |
| Cover | 80 | 0 | 3 | 1.76 | .931 | -.372 | .269 |
| Focus | 80 | 0 | 3 | 2.17 | .911 | -.976 | .269 |
| Preference | 80 | 0 | 3 | 2.94 | .368 | -7.039 | .269 |
| Reflexive | 80 | 1 | 3 | 2.64 | .579 | -1.363 | .269 |
| Repetition | 80 | 1 | 3 | 2.93 | .348 | -4.886 | .269 |
| Excess2 | 80 | 0 | 3 | 2.60 | .722 | -1.911 | .269 |
| Valid N (listwise) | 80 | | | | | | |

a. PC = Yes

Table 50. Comparison of Gender Performance

**ANOVA**

| PC | | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| No | PreTestScore | Between Groups | .817 | 1 | .817 | .065 | .802 |
| | | Within Groups | 174.933 | 14 | 12.495 | | |
| | | Total | 175.750 | 15 | | | |
| | PostTestScore | Between Groups | .104 | 1 | .104 | .017 | .898 |
| | | Within Groups | 84.833 | 14 | 6.060 | | |
| | | Total | 84.938 | 15 | | | |
| Yes | PreTestScore | Between Groups | 21.025 | 1 | 21.025 | .813 | .373 |
| | | Within Groups | 982.350 | 38 | 25.851 | | |
| | | Total | 1003.375 | 39 | | | |
| | PostTestScore | Between Groups | 8.100 | 1 | 8.100 | .267 | .608 |
| | | Within Groups | 1151.900 | 38 | 30.313 | | |
| | | Total | 1160.000 | 39 | | | |

## 9.9 ANOVA Test Scores by Profile

Table 51. Comparison of Education Level

**ANOVA**

| PC | | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| No | PreTestScore | Between Groups | 18.150 | 1 | 18.150 | 1.612 | .225 |
| | | Within Groups | 157.600 | 14 | 11.257 | | |
| | | Total | 175.750 | 15 | | | |
| | PostTestScore | Between Groups | 5.104 | 1 | 5.104 | .895 | .360 |
| | | Within Groups | 79.833 | 14 | 5.702 | | |
| | | Total | 84.938 | 15 | | | |
| Yes | PreTestScore | Between Groups | 116.743 | 2 | 58.372 | 2.436 | .101 |
| | | Within Groups | 886.632 | 37 | 23.963 | | |
| | | Total | 1003.375 | 39 | | | |
| | PostTestScore | Between Groups | 106.342 | 2 | 53.171 | 1.867 | .169 |
| | | Within Groups | 1053.658 | 37 | 28.477 | | |
| | | Total | 1160.000 | 39 | | | |

Table 52. VR Age Range

**Descriptives**

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean Lower Bound | 95% Confidence Interval for Mean Upper Bound | Min | Max |
|---|---|---|---|---|---|---|---|---|---|
| PreTestScore | 18-24 | 6 | 25.50 | 2.429 | .992 | 22.95 | 28.05 | 22 | 28 |
| | 25-34 | 10 | 21.70 | 3.199 | 1.012 | 19.41 | 23.99 | 16 | 25 |
| | Total | 16 | 23.13 | 3.423 | .856 | 21.30 | 24.95 | 16 | 28 |
| PostTestScore | 18-24 | 6 | 26.50 | 1.378 | .563 | 25.05 | 27.95 | 25 | 28 |
| | 25-34 | 10 | 24.00 | 2.404 | .760 | 22.28 | 25.72 | 20 | 27 |
| | Total | 16 | 24.94 | 2.380 | .595 | 23.67 | 26.21 | 20 | 28 |

Table 53. Comparison of Eng. Proficiency

**ANOVA**

| PC | | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| No | PreTestScore | Between Groups | 2.694 | 2 | 1.347 | .101 | .904 |
| | | Within Groups | 173.056 | 13 | 13.312 | | |
| | | Total | 175.750 | 15 | | | |
| | PostTestScore | Between Groups | 8.715 | 2 | 4.358 | .743 | .495 |
| | | Within Groups | 76.222 | 13 | 5.863 | | |
| | | Total | 84.938 | 15 | | | |
| Yes | PreTestScore | Between Groups | 116.284 | 2 | 58.142 | 2.425 | .102 |
| | | Within Groups | 887.091 | 37 | 23.975 | | |
| | | Total | 1003.375 | 39 | | | |
| | PostTestScore | Between Groups | 138.188 | 2 | 69.094 | 2.502 | .096 |
| | | Within Groups | 1021.812 | 37 | 27.617 | | |
| | | Total | 1160.000 | 39 | | | |

Table 54. VR Age Range

**Descriptives**

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean Lower Bound | 95% Confidence Interval for Mean Upper Bound | Min | Max |
|---|---|---|---|---|---|---|---|---|---|
| PreTestScore | 18-24 | 6 | 25.50 | 2.429 | .992 | 22.95 | 28.05 | 22 | 28 |
| | 25-34 | 10 | 21.70 | 3.199 | 1.012 | 19.41 | 23.99 | 16 | 25 |
| | Total | 16 | 23.13 | 3.423 | .856 | 21.30 | 24.95 | 16 | 28 |
| PostTestScore | 18-24 | 6 | 26.50 | 1.378 | .563 | 25.05 | 27.95 | 25 | 28 |
| | 25-34 | 10 | 24.00 | 2.404 | .760 | 22.28 | 25.72 | 20 | 27 |
| | Total | 16 | 24.94 | 2.380 | .595 | 23.67 | 26.21 | 20 | 28 |

Table 55. Comparison of Eng. Proficiency

**ANOVA**

| PC | | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| No | PreTestScore | Between Groups | 2.694 | 2 | 1.347 | .101 | .904 |
| | | Within Groups | 173.056 | 13 | 13.312 | | |
| | | Total | 175.750 | 15 | | | |
| | PostTestScore | Between Groups | 8.715 | 2 | 4.358 | .743 | .495 |
| | | Within Groups | 76.222 | 13 | 5.863 | | |
| | | Total | 84.938 | 15 | | | |
| Yes | PreTestScore | Between Groups | 116.284 | 2 | 58.142 | 2.425 | .102 |
| | | Within Groups | 887.091 | 37 | 23.975 | | |
| | | Total | 1003.375 | 39 | | | |
| | PostTestScore | Between Groups | 138.188 | 2 | 69.094 | 2.502 | .096 |
| | | Within Groups | 1021.812 | 37 | 27.617 | | |
| | | Total | 1160.000 | 39 | | | |

Table 56. Static Action Scores by Gender

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| SumOfLook | Between Groups | 20904.024 | 1 | 20904.024 | .601 | .448 |
| | Within Groups | 661374.929 | 19 | 34809.207 | | |
| | Total | 682278.952 | 20 | | | |
| SumOfTouch | Between Groups | 1.167 | 1 | 1.167 | .024 | .880 |
| | Within Groups | 941.786 | 19 | 49.568 | | |
| | Total | 942.952 | 20 | | | |
| SumOfPlace | Between Groups | 427.524 | 1 | 427.524 | 1.036 | .322 |
| | Within Groups | 7841.143 | 19 | 412.692 | | |
| | Total | 8268.667 | 20 | | | |

Table 57. PC Static Action Scores by Education Level

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| SumOfLook | Between Groups | 39702.315 | 1 | 39702.315 | 1.174 | .292 |
| | Within Groups | 642576.638 | 19 | 33819.823 | | |
| | Total | 682278.952 | 20 | | | |
| SumOfTouch | Between Groups | 84.152 | 1 | 84.152 | 1.862 | .188 |
| | Within Groups | 858.800 | 19 | 45.200 | | |
| | Total | 942.952 | 20 | | | |
| SumOfPlace | Between Groups | 1261.867 | 1 | 1261.867 | 3.422 | .080 |
| | Within Groups | 7006.800 | 19 | 368.779 | | |
| | Total | 8268.667 | 20 | | | |

## 9.10 VR Action T-Tests

Table 58. T-Test VR by Gender

**Independent Samples Test**

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Confidence Interval of the Difference | |
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| LookScore | Equal variances assumed | 7.033 | .019 | .171 | 14 | .867 | 49.133 | 287.053 | -566.534 | 664.801 |
| | Equal variances not assumed | | | .211 | 12.107 | .836 | 49.133 | 232.630 | -457.225 | 555.492 |
| TouchScore | Equal variances assumed | 1.719 | .211 | .640 | 14 | .533 | 6.867 | 10.738 | -16.163 | 29.896 |
| | Equal variances not assumed | | | .583 | 7.984 | .576 | 6.867 | 11.781 | -20.309 | 34.043 |
| PlaceScore | Equal variances assumed | .002 | .968 | .059 | 14 | .954 | .433 | 7.329 | -15.286 | 16.153 |
| | Equal variances not assumed | | | .060 | 11.259 | .953 | .433 | 7.201 | -15.372 | 16.238 |

Table 59. T-Test VR by Age

**Independent Samples Test**

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Confidence Interval of the Difference | |
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| LookScore | Equal variances assumed | .489 | .496 | -.116 | 14 | .909 | -27.133 | 233.094 | -527.070 | 472.803 |
| | Equal variances not assumed | | | -.110 | 8.975 | .915 | -27.133 | 246.201 | -584.316 | 530.049 |
| TouchScore | Equal variances assumed | .825 | .379 | -.413 | 14 | .686 | -4.467 | 10.828 | -27.690 | 18.756 |
| | Equal variances not assumed | | | -.465 | 13.941 | .649 | -4.467 | 9.606 | -25.079 | 16.145 |
| PlaceScore | Equal variances assumed | 1.174 | .297 | -.575 | 14 | .574 | -4.167 | 7.245 | -19.706 | 11.373 |
| | Equal variances not assumed | | | -.624 | 13.261 | .543 | -4.167 | 6.679 | -18.566 | 10.233 |

Table 60. T-Test VR by Education

**Independent Samples Test**

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | 95% Confidence Interval of the Difference | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| LookScore | Equal variances assumed | .229 | .640 | -1.429 | 14 | .175 | -311.267 | 217.864 | -778.539 | 156.006 |
| | Equal variances not assumed | | | -1.455 | 11.272 | .173 | -311.267 | 213.973 | -780.837 | 158.304 |
| TouchScore | Equal variances assumed | .022 | .883 | -.704 | 14 | .493 | -7.533 | 10.706 | -30.494 | 15.428 |
| | Equal variances not assumed | | | -.695 | 10.247 | .503 | -7.533 | 10.844 | -31.616 | 16.549 |
| PlaceScore | Equal variances assumed | .003 | .960 | -.993 | 14 | .338 | -7.033 | 7.085 | -22.229 | 8.163 |
| | Equal variances not assumed | | | -.967 | 9.818 | .357 | -7.033 | 7.274 | -23.282 | 9.215 |

Table 61. T-Test VR by Eng Proficiency

**Independent Samples Test**

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 95% Confidence Interval of the Difference | |
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | Lower | Upper |
| LookScore | Equal variances assumed | .051 | .825 | 1.576 | 13 | .139 | 318.389 | 202.016 | -118.040 | 754.818 |
| | Equal variances not assumed | | | 1.494 | 8.931 | .170 | 318.389 | 213.109 | -164.262 | 801.040 |
| TouchScore | Equal variances assumed | .354 | .562 | -.716 | 13 | .487 | -8.056 | 11.252 | -32.365 | 16.254 |
| | Equal variances not assumed | | | -.651 | 7.627 | .534 | -8.056 | 12.375 | -36.837 | 20.725 |
| PlaceScore | Equal variances assumed | .012 | .914 | -.788 | 13 | .445 | -5.722 | 7.258 | -21.401 | 9.957 |
| | Equal variances not assumed | | | -.752 | 9.151 | .471 | -5.722 | 7.607 | -22.888 | 11.443 |

## 9.11 Effect Sizes for Adaptive versus Static Sense Scores

Table 62. Adaptive versus Static Effect Sizes

**Paired Samples Effect Sizes**

| Adaptive | | | | Standardizer[a] | Point Estimate | 95% Confidence Interval Lower | Upper |
|---|---|---|---|---|---|---|---|
| N | Pair 1 | Sess1Proto - Sess2Proto | Cohen's d | .41249 | .058 | -.245 | .360 |
| | | | Hedges' correction | .41631 | .057 | -.243 | .357 |
| | Pair 2 | Sess1Excess1 - Sess2Excess1 | Cohen's d | .59274 | -.201 | -.505 | .106 |
| | | | Hedges' correction | .59823 | -.199 | -.501 | .105 |
| | Pair 3 | Sess1OtherSide - Sess2OtherSide | Cohen's d | .40682 | -.176 | -.479 | .130 |
| | | | Hedges' correction | .41059 | -.174 | -.475 | .129 |
| | Pair 4 | Sess1Completion - Sess2Completion | Cohen's d | .21554 | -.221 | -.526 | .087 |
| | | | Hedges' correction | .21754 | -.219 | -.521 | .086 |
| | Pair 5 | Sess1Transfer - Sess2Transfer | Cohen's d | .34165 | -.209 | -.514 | .098 |
| | | | Hedges' correction | .34482 | -.207 | -.509 | .097 |
| | Pair 6 | Sess1Control - Sess2Control | Cohen's d | .58236 | -.082 | -.384 | .222 |
| | | | Hedges' correction | .58775 | -.081 | -.381 | .220 |
| | Pair 7 | Sess1Temporal - Sess2Temporal | Cohen's d | .21554 | -.221 | -.526 | .087 |
| | | | Hedges' correction | .21754 | -.219 | -.521 | .086 |
| | Pair 8 | Sess1Cover - Sess2Cover | Cohen's d | .61154 | -.545 | -.867 | -.218 |
| | | | Hedges' correction | .61721 | -.540 | -.859 | -.216 |
| | Pair 9 | Sess1Focus - Sess2Focus | Cohen's d | .40682 | -.176 | -.479 | .130 |
| | | | Hedges' correction | .41059 | -.174 | -.475 | .129 |
| | Pair 11 | Sess1Reflexive - Sess2Reflexive | Cohen's d | .26943 | -.088 | -.391 | .215 |
| | | | Hedges' correction | .27192 | -.088 | -.387 | .213 |
| | Pair 13 | Sess1Excess2 - Sess2Excess2 | Cohen's d | .34838 | -.068 | -.371 | .235 |
| | | | Hedges' correction | .35161 | -.068 | -.367 | .233 |
| Y | Pair 1 | Sess1Proto - Sess2Proto | Cohen's d | .66889 | .064 | -.171 | .298 |
| | | | Hedges' correction | .67255 | .064 | -.170 | .297 |
| | Pair 2 | Sess1Excess1 - Sess2Excess1 | Cohen's d | .39902 | -.036 | -.270 | .199 |
| | | | Hedges' correction | .40120 | -.036 | -.269 | .198 |
| | Pair 3 | Sess1OtherSide - Sess2OtherSide | Cohen's d | .58907 | .049 | -.186 | .283 |
| | | | Hedges' correction | .59229 | .048 | -.185 | .281 |
| | Pair 4 | Sess1Completion - Sess2Completion | Cohen's d | .46067 | -.155 | -.390 | .081 |
| | | | Hedges' correction | .46319 | -.154 | -.388 | .081 |
| | Pair 5 | Sess1Transfer - Sess2Transfer | Cohen's d | .53530 | -.107 | -.341 | .129 |
| | | | Hedges' correction | .53823 | -.106 | -.339 | .128 |
| | Pair 6 | Sess1Control - Sess2Control | Cohen's d | .56172 | -.102 | -.336 | .134 |
| | | | Hedges' correction | .56479 | -.101 | -.334 | .133 |
| | Pair 7 | Sess1Temporal - Sess2Temporal | Cohen's d | .40083 | -.285 | -.523 | -.045 |
| | | | Hedges' correction | .40302 | -.284 | -.520 | -.045 |
| | Pair 8 | Sess1Cover - Sess2Cover | Cohen's d | .40799 | -.210 | -.446 | .028 |
| | | | Hedges' correction | .41023 | -.209 | -.444 | .027 |
| | Pair 9 | Sess1Focus - Sess2Focus | Cohen's d | .70034 | -.184 | -.419 | .053 |
| | | | Hedges' correction | .70418 | -.183 | -.417 | .053 |
| | Pair 11 | Sess1Reflexive - Sess2Reflexive | Cohen's d | .43382 | -.033 | -.267 | .202 |
| | | | Hedges' correction | .43619 | -.033 | -.266 | .200 |
| | Pair 13 | Sess1Excess2 - Sess2Excess2 | Cohen's d | .43857 | -.358 | -.599 | -.115 |
| | | | Hedges' correction | .44097 | -.356 | -.596 | -.115 |
| | Pair 10 | Sess1Preference - Sess2Preference | Cohen's d | .26881 | .053 | -.181 | .287 |
| | | | Hedges' correction | .27028 | .053 | -.180 | .286 |
| | Pair 12 | Sess1Repetition - Sess2Repetition | Cohen's d | .28921 | .198 | -.040 | .433 |
| | | | Hedges' correction | .29080 | .197 | -.039 | .431 |

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.
Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.