Presented during the 'Computer Science and Electronic Engineering Conference 2019' (CEEC'19) held at the University of Essex, 18th–20th September 2019.

Towards Dynamically Adaptable Immersive Spaces for Learning

Michiel Smuts
School of Computer Science and Electronic Engineering (CSEE)
The University of Essex
Colchester, UK
ms17972@essex.ac.uk

Michael Gardner
School of Computer Science and Electronic Engineering (CSEE)
The University of Essex
Colchester, UK
mgardner@essex.ac.uk

Victor Callaghan
School of Computer Science and Electronic Engineering (CSEE)
The University of Essex
Colchester, UK
vic@essex.ac.uk

Adela Ganem Gutierrez
Department of Language and Linguistics
The University of Essex
Colchester, UK
aganem@essex.ac.uk

Abstract. This paper describes the difficulties prepositions pose for students learning English as a second language and proposes novel solutions for teaching based on Virtual Reality (VR), and environments using Artificial Intelligence (AI). It identifies the synergy between Cognitive Linguistics (CL) and VR and describes how VR may be applied to Second Language Acquisition (SLA). This is followed by a proposed integration of AI into a VR environment. The paper then goes on to describe a novel method for creating an intelligent teaching environment for SLA, based on cloning student behaviour, and gives details of the process and a simplified functional example. **(***Abstract***)**

Keywords—Dynamic User Interface, Behaviour Cloning, Dynamic Environments, Intelligent Environments, Responsive Environments, Machine Learning, Second Language Acquisition ***(key words)***

I. Introduction

This paper investigates whether VR and AI can be used to find an improved method for teaching prepositions to students learning English as a second language. After outlining the specific challenges English prepositions pose for foreign language students, and providing a short overview of traditional teaching methods, the paper seeks to evaluate VR as a teaching medium based on CL. It then proposes a novel method for integrating AI into a VR environment to create a dynamic learning environment based on student behaviour. The conclusion focuses on the implications of the work completed to date and issues yet to be resolved.

II. The Challenges Posed by English Prepositions

Second Language (L2) learners often have difficulties understanding the use of English prepositions [1]–[5]. Linguists and psychologists have explained the difficulties by describing several contributing factors, for example: 1) Native grammar (L1) rules are an embedded mental schema for grammar and represent a form of behavioural conditioning. L1 rules interfere with the acquisition of second language (L2) rules [6, p. 4]. 2) English prepositions are syntactically idiosyncratic, rarely following a predictable pattern, which makes them difficult to apply to new situations [7]. 3) Many prepositions are semantically polysemic resulting in multiple meanings dictated by context [8, p. 445]. 4) Often the preposition will not contribute substantially to the meaning of the sentence compared to (incorrect) alternatives [9, p. 196]. 5) Morphologically prepositions are difficult to recognise as they can contain few syllables making them difficult to identify in speech [7]. 6) L1 languages may not have a direct translation for English prepositions and use instead inflection or other structural replacements [10]. This can be inconsistent with other processes used when, learning for example, vocabulary. 7) Cultural lexical priming can create confusion when community traditions defining semantic associations differ substantially from English semantic associations [11, p. 55]. 8) Structural priming (where L2 speakers repeat the structure of the previously heard sentence), while possibly unconscious, is thought to be an important part of learning syntactic structure, though as previously noted (item 2 in this list), prepositions are syntactically idiosyncratic and the resulting sentences from any unconscious structural priming may be confusingly incorrect [12]. As well as prepositions being challenging for English Second Language (ESL) students, prepositions are notoriously difficult to teach [7], [8], [13]. According to Tyler & Evans [14] some traditional teaching approaches emphasise core meanings of prepositions rather than their abstract meanings, some treat prepositions and their extensions as inventory items to be learned by rote, some provide a "rule plus exception" approach, and some a vague relationship between spatial and non-spatial exceptions [15]. Further, it may be difficult to design definitive teaching methods based on the way students learn because learning theory is fragmented. Even when theories are grouped into broad categories such as Functionalism, Associationism, Cognitive, Neurophysiological and Evolutionary, they overlap with no one theory explaining the overall process [16], and of course there is a debate over whether learning a language is a distinct process from general learning [16], [17]. VR in teaching (based on the Oculus Rift) has limited evidence to support improved learning outcomes [18]–[20] and little is known about the use of AI in such teaching environments.

III. Virtual Reality (Oculus Rift) and Second Language Acquisition (SLA)

To date the research has focused on creating a VR environment which can be used to teach prepositions and includes an optional AI component. To use VR as a method for teaching prepositions it was necessary to identify a learning theory which was consistent with the affordances of VR. Cognitive learning theory emphasises the importance of a range of inputs which influence learners and is in keeping with Leontiev's [21], [22, p. 362] view that "real life" is a key factor in the pedagogical development of the mind. An approximation of real life within a VR environment allows for the previously mentioned "range of inputs" to be adjusted. If real life is indeed a "key factor in the pedogeological development of the mind" then control of the inputs should allow the VR environment to influence the learning process. It is widely understood that comprehensible and appropriately contextualized second language input is necessary for learning to take place [23, p. 164], and the ability to provide context in a virtual world should prove beneficial in teaching a second language. In VR there are two sets of conceptual structures at play; one is the designed world and the way in which it interacts with the user, and the other is the cognitive semantic version of conceptual structures, namely the structures which are a manifestation of linguistic meaning created in the users mind[24]. Further, VR supports embodied cognition because it allows interaction with the world [8, p. 452], [25, p. 27], [26, p. 157], permitting existing mental schemas of bodily experience to be overlaid onto the virtual world which is consistent with cognitive learning theory. VR also allows the student to experience the consequences of their actions by allowing the augmentation of both negative and positive feedback. For example; the concept "containment" is a consequence of being physically locked in a room, and in VR the feedback consequence for trying to leave that room might be that the light exponentially decreases. The metaphorical projection of "containment" could be to be contained by the state of being in a relationship, represented in VR with the same consequences if the user tries to "leave" the contained state of a relationship. VR is able to demonstrate both forms of the preposition "in" in the same way for conceptual and physical examples using the consequence afforded by the environment. Using the affordances of VR for representing cognitive semantic meaning it should be possible to apply the environment to teaching English prepositions to L2 language students. The proposed VR teaching environment is designed to be reduced to individual prepositional challenges, as described by the CL information processing model. This has advantages for designers creating learning environments, as it considers complex behaviour to be built on simple processes, and is therefore consistent with curriculum learning where complex tasks are reduced to their simple components [16]. Superficially this reductionist view of "simple processes" might seem to be in conflict with Galperin's cultural historical theory (founded on the work of Vygotsky and Leontiev), which seeks to avoid atomising learning activity so as not to lose sight of the overall process [21]. Whilst this is a danger that designers of learning environments need to be aware of, Galperin himself believed in the value of activities that focused on the essential characteristics of concepts. In effect, progressive investigative steps towards understanding a concept would not necessarily mean that the number of inputs or level of activity are reduced. Galperin further suggested that "materialised actions (using models, simulations, animations, schemes, etc.)" [21], were necessary in order to create new types of internal psychological activity. The use of VR in learning is consistent with Galperin and constructionist CL theorists who favour explaining knowledge acquisition from inductive learning (generalisation from examples) as proposed by Carroll [27]. Whether this approach will simply reproduce the learning outcomes already achieved by existing teaching methods or improve learning outcomes, requires further investigation.

IV. Artificial Intelligence, Virtual Reality (Oculus Rift) and Second Language Acquisition (SLA)

As mentioned previously, the current VR learning environment is intended to use a "range of inputs" to encourage inductive learning. Within the VR environment AI has been included in the form of independent machine learning agents attached to items such as movable objects and lighting. When a student is attempting prepositional challenges, these agents guide the student's attention. For example, agents attached to objects change their colour saturation (Fig.1) to manipulate the visual hierarchy and draw the student's attention to the top right corner of the image. When learning technology is no longer in the forefront of a student'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 student cognition [30]–[32]. Augusto et al [31] describes ambient intelligence as "assisting in a sensible way" [33] implying that the environment has an ability to recognise when it is allowed or appropriate to help and will do this automatically without external intervention.

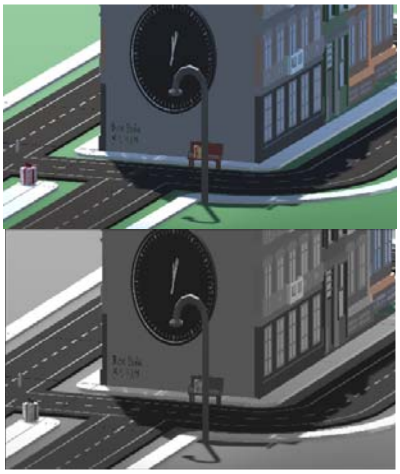


Fig. 1. Changes in Visual Hierarchy

This change represents an "input" as described previously when discussing Cognitive Learning. Understanding what to change to improve the students learning outcome is the challenge.

A. *Proposed Solution: A Novel Method*

One of the main challenges of this research is to teach agents in the environment to recognise patterns in the decisions made by students (their "policy" for making decisions) when they are attempting to solve problems. As mentioned in the introduction, SLA theory suggests that native grammar rules are an embedded mental schema and represent a form of behavioural conditioning, which may interfere with the acquisition of L2 rules. Further, according to cognitive learning theory this conditioning will be informed by environmental (spatial) cues or inputs [28]. The novel method for this research is to create a clone of the student's "policy" and use this clone to train the environment agents. This copy of a student's learning approach is inherently static, in that it represents the approach to learning at the time the clone was made. The student's metacognition (their understanding of their own thought processes) should result in a changing approach to learning during the learning process, and this might suggest that the trained environment would quickly become redundant. However, having been trained by the clone of the student, the environment will only intervene where the student incorrectly allows L1 rules to override the L2 rules. In effect, the environment is attempting to make itself redundant. When it is redundant the student is correctly using the L2 rules.

B. Creating and Controlling Virtual Reality Environments

This method has been created using the Unity Engine [29] which was selected because of its ability to create and control 3D environments, integrate VR equipment such as the Oculus Rift , and access machine learning algorithms and the tools needed to train those algorithms such as TensorFlow. Unity allows reasonably rapid development and places all the elements of VR and Machine Learning within the scope of a single researcher.

V. Novel Method

The method is divided into four stages (Fig. 2), the first three stages are completed for each individual agent:

1) Data repository creation (observing the SLA student and remembering what they do).

2) Behavioural cloning using a supervised learning algorithm (creating a mini digital student that makes decisions in a similar way to the real student).

3) Teaching the environment agents using a reinforcement learning algorithm (using the digital student to test scenarios to identify the best teaching approach).

4) Using the environment agents to teach students with similar L1 schemas.

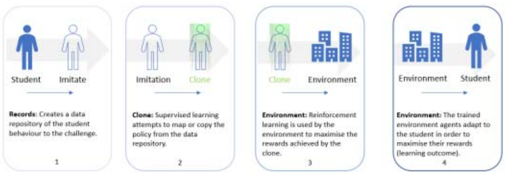
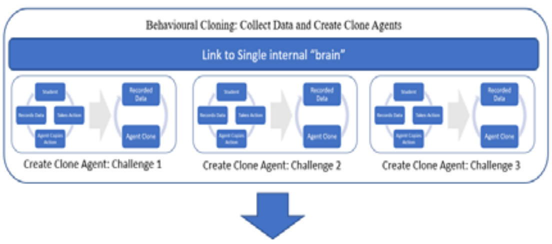


Figure 2. Separated Processing Stages

Figure 3 shows a system diagram for the overall process.



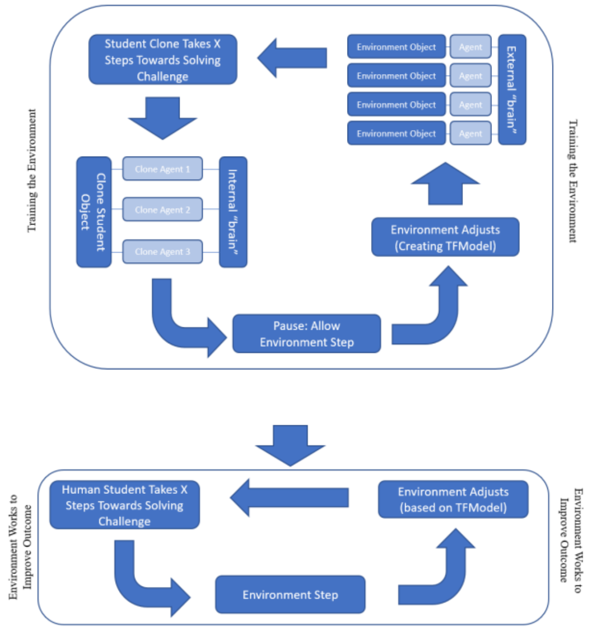


Figure 3. System Diagram

Example: In a test environment where a student is expected to interact with clocks on a bench (fig.4)

Figure 4. Dynamic Clocks on Bench

The dynamic objects (in this case all clocks) have their own machine learning agents linked to a single neural net model for the whole environment. All these objects could make small changes to guide the student based on their own observations. In this example an object (clock) might recognise that it has been looked at, as well as note the state of the challenge at that moment. The algorithm receiving the observations from (all) the agents might then decide that the object has completed its role and consequently change the objects position so that it no longer faces the student (Fig. 5) and is less likely to attract the student's attention. This is an ambient change intended to go unnoticed by the student.

Figure 5. Dynamic Clock Adjusted

VI. Training Illustration

The following example is a simplified illustration (not based on preposition learning), built to test the premise that agent-controlled objects will act to support a clone's goals and further, to understand the processing resources needed to implement any proposed solution. In the diagram below (Fig. 6), the orange box is attached to an agent which has behaviour cloned from a student. The objective of the orange box is to move to the red sphere. The three walls have been given agents which observe the box, the sphere, and the other walls.

Figure 6. Simplified Example

The walls can move and scale as they wish. The correct solution for the walls to achieve optimal learning is to scale down to nothing and effectively move out of the way of the orange box. In this way the environment can adapt itself to the optimum configuration for the success of the clone. The walls exhibit collective behaviour or a type of consensus decision making even though they are driven by their own individual agents, because they are being driven by the same minority actions i.e. the clone [34].

This simplified model was built to understand possible scaling constraints which might cause larger environments to fail. The orange square was able to reach the red sphere and avoid the walls after ten minutes of training. Those ten minutes were used as the decision-making template to create a digital clone. It took 55,000 iterations of the test environment before the clone had a cloning loss less than 0.5% (the lower the cloning loss, the closer to the original behaviour) and be considered potentially useful for training the environment (fig. 7 shows two lines representing two training attempts).

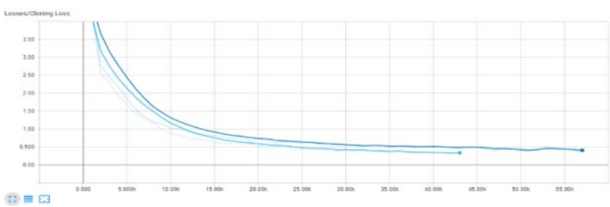


Figure 7. Training Clone Agents

Once the clone was trained, the environment agents (in this case the 3 horizontal walls Fig. 6) were trained using reinforcement learning. Reinforcement learning uses positive and negative rewards to guide agents towards the desired goal. In this case negative rewards were given for each step (encouraging the agents to find a solution quickly) and positive rewards when the orange cube moved closer to the red sphere. In figure 8 the dark blue line shows the reward profile of the agents attached to the walls as they learn to "help" the clone. The light blue line shows the reward profile of a wall with no agent attached i.e. it reflects the reward profile of the clone itself and a static environment. In this instance it took about 40,000 iterations before the environment (wall) agents were trained.

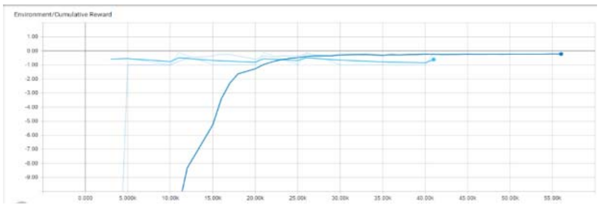


Figure 8. Reward Given to Walls

The simplified environment shows that a large number of iterations are required for an environment with only three elements. This indicates that environments with hundreds of elements will require significant processing power for each prepositional challenge.

VII. Conclusion

Based on the research so far, we claim that VR based on CL theory may be an effective way of teaching prepositions in SLA. However, to represent prepositional states and enable students to interact with them, each representation needs careful and creative consideration. For example, representing the prepositions "to" and "for" in the sentence the ball rolls to/for the hills, according to Tyler [35], the sense of "to" is that there is no intent i.e. "the ball rolls to the hills", the ball has no intent to get to the hills, it is just rolling to the hills. This is distinct from "the man runs for the hills", where the man described has an intent to get to the hills. Tyler describes this intent as having a secondary purpose. If a student uses the preposition "for" where the focus object (in this case the ball) cannot have intent, instead of creating some form of failed state feedback, the current research environment anthropomorphizes the ball endowing it with the ability to have intent. While this is entertaining, it is not yet clear whether adjusting the environment to fit the students answer, and changing the consequences of their answer, is enough to give the student a sense of meaning of "for". In future a more sophisticated consequence which includes making a secondary purpose explicit as well as refining the student interaction with the challenge may be required. The effect of AI in VR on learning outcomes will need to be established through the creation of control scenes and challenges. Performance benchmarks for the number of agent-controlled objects need to be established as the current research suggests there may be significant demands on processing power. Further, at this stage no student interaction with agent-controlled objects has been tested. If an object is intended to be diegetic then it should be possible for the student to interact with it. Given that objects may include machine learning agents it will be necessary to identify resulting unintended consequences or paradoxes. Additionally, key performance indicators such as the optimal time between environment changes and the type of changes (i.e. should they be limited to diegetic changes) among others, will need to be established. The next stage of this research is to build, test, and iterate environments, both with and without AI agents, with the aim of initiating experiments with SLA students.

REFERENCES

[1] R. Lado 1915-1995, “Linguistics across cultures ; applied linguistics for language teachers / With a foreword by Charles C. Fries.” pp. 0-0 SE-.

[2] M. Chodorow, M. Gamon, and J. Tetreault, “The utility of article and preposition error correction systems for English language learners: Feedback and assessment,” Lang. Test., vol. 27, no. 3, pp. 419–436, 2010.

[3] S. Jarvis and T. Odlin, “Morphological Type, Spatial Reference, and Language Transfer,” Ssla, vol. 22, pp. 535–556, 2018.

[4] J. Autret, “The Verbal Idea in Anglo-Saxon Verbs with Prepositions , and Its Translation into Romance Languages Author (s): Source : The French Review , Vol . 18 , No . 6 (May , 1945), pp . 350-354 Published by : American Association of Teachers of Fr,” vol. 18, no. 6, pp. 350–354, 2019.

[5] D. Jach, “A Usage-Based Approach to Preposition Placement in English as a Second Language,” Lang. Learn., vol. 68, no. 1, pp. 271–304, 2018.

[6] A. S. Dera, “English Spatial Prepositions with Particular Reference to Arabic-Speaking Learners By,” 1994.

[7] A. Kilimci, “Integrating Cognitive Linguistics Insights into Data-Driven Learning: Teaching Vertical Prepositions,” J. Lang. Linguist. Stud., vol. 13, no. 2, pp. 681–719, 2017.

[8] M. H. I. Wong, H. Zhao, and B. MacWhinney, “A Cognitive Linguistics Application for Second Language Pedagogy: The English Preposition Tutor,” Lang. Learn., vol. 68, no. 2, pp. 438–468, 2018.

[9] R. Kao, “Where have the prepositions gone ? A study of English prepositional verbs and ...,” Appl. Linguist., vol. 39, no. 1987, pp. 195–215, 2001.

[10] M. Celce-Murcia, “The grammar book : an ESL/EFL teacher’s course / Marianne Celce-Murcia, Diane Larsen-Freeman with Howard Williams.” pp. 0–1.

[11] Y. KAMAKURA, “COLLOCATION AND PREPOSITION SENSE : A PHRASEOLOGICAL APPROACH TO THE COGNITION OF POLYSEMY by YOSHIHITO KAMAKURA A thesis submitted to the University of Birmingham for the degree of DOCTOR OF PHILOSOPHY Department of English School of English , Drama and,” no. February, 2011.

[12] M. A. Conroy and I. Antón-Méndez, “A preposition is something you can end a sentence with: Learning English stranded prepositions through structural priming,” Second Lang. Res., vol. 31, no. 2, pp. 211–237, 2015.

[13] B. P. Hung, V. Truong, and N. V. Nguyen, “Students’ responses to CL-based teaching of english prepositions,” Egit. Arastirmalari - Eurasian J. Educ. Res., vol. 2018, no. 73, pp. 41–58, 2018.

[14] A. Tyler and C. Mueller, “Applying Cognitive Linguistics to Learning the Semantics of English to , for and at : An Experimental Investigation Resumen,” no. Cl, pp. 181–206.

[15] Y. Lam, “The Acquisition of Prepositional Meanings in L2 Spanish The Acquisition of Prepositional Meanings in L2 Spanish,” Can. J. Appl. Linguist., vol. 21, pp. 1–22, 2018.

[16] M. Pienemann 1951-, “Language processing and second language development : processability theory / Manfred Pienemann.” pp. 0–4.

[17] N. A. Vahey, M. Bennett, and R. Whelan, “Conceptual advances in the cognitive neuroscience of learning: Implications for relational frame theory,” J. Context. Behav. Sci., vol. 6, no. 3, pp. 308–313, 2017.

[18] H. H. Yang, Handbook of Research on Practices and Outcomes in E-Learning. 2010.

[19] Z. Merchant, E. T. Goetz, L. Cifuentes, W. Keeney-Kennicutt, and T. J. Davis, “Effectiveness of virtual reality-based instruction on students’ learning outcomes in K-12 and higher education: A meta-analysis,” Comput. Educ., vol. 70, pp. 29–40, Jan. 2014.

[20] M. J. Peña-Ríos, Anasol; Callaghan, Vic; Gardner, Michael; Alhaddad, “xReality interactions within a mixed reality learning environments,” 3rd Eur. Immersive Educ. Summit, 2013.

[21] I. Engeness and A. Lund, “Learning for the future: Insights arising from the contributions of Piotr Galperin to the cultural-historical theory,” Learn. Cult. Soc. Interact., no. xxxx, pp. 1–11, 2018.

[22] P. Lantolf and M. Poehner, The Routledge Handbook of Sociocultural Theory and Second Language Development. 2018.

[23] R. Mitchell and F. Myles, Second Language Learning Theories. London: Hodder, 2004.

[24] V. Evans et al., Cognitive Linguistics : An Introduction, no. 2006. Edinburgh: Edinburgh University Press, 2006.

[25] G. Lakoff, “The nature of cognitive linguistics : Assumptions and commitments,” no. 1, pp. 27–53, 2019.

[26] V. Evans and M. Green, “What is cognitive semantics ?,” Cogn. Linguist. An Introd., pp. 156–175, 2006.

[27] P. Maftoon and L. T. Esfandiari, “Carroll’s Autonomous Induction Theory: Combining Views from UG and Information Processing Theories,” J. Lang. Teach. Res., vol. 6, no. 2, p. 423, 2015.

[28] P. J. Robinson and N. C. Ellis, Handbook of Cognitive Linguistics and Second Language Acquisition. New York: Routledge, 2008.

[29] A. Juliani et al., “Unity: A General Platform for Intelligent Agents,” pp. 1–18, 2018.

[30] M. Weiser, “The computer for the 21st Century,” IEEE Pervasive Comput., vol. 1, no. 1, pp. 19–25, 2002.

[31] J. C. Augusto, V. Callaghan, D. Cook, A. Kameas, and I. Satoh, “‘Intelligent Environments: a manifesto,’” Human-centric Comput. Inf. Sci., vol. 3, no. 1, pp. 1–18, 2013.

[32] K. Kakavelakis and T. Edwards, “Situated learning theory and agentic orientation: A relational sociology approach,” Manag. Learn., vol. 43, no. 5, pp. 475–494, 2012.

[33] H. Nakashima, A. Hamid, and J. C. Augusto, Handbook of ambient intelligence and smart environments. New York: Springer, 2010.

[34] Z. Qin, F. Khawar, and T. Wan, “Neurocomputing Collective game behavior learning with probabilistic graphical models,” Neurocomputing, vol. 194, pp. 74–86, 2016.

[35] V. Tyler, Andrea; Evans, The Semantics of English Prepositions, no. 5. Cambridge: Cambridge University Press, 2003.