Presented at the 5th 'Immersive Learning Research Network Conference (iLRN'2019) held in the University of Westminster, London UK, June 23–27, 2019

A Generalized Pedagogical Framework for Creating Mixed-Mode Role-Play in Multi-User Virtual Environments

Enas Jambi[1,2(✉)], Michael Gardner[1] , and Victor Callaghan[1]

[1] University of Essex, Colchester, UK
{eamjam,mgardner,vic}@essex.ac.uk
[2] University of Jeddah, Jeddah, Saudi Arabia

Abstract. Science students face considerable challenges when attempting to absorb and visualize abstract concepts presented to them in the classroom; educators use a number of methods to support their students in this regard. Our focus is on two such methods currently being used by educators: role-play and 3D simulation; these are designed to immerse the student in the learning process. Both methods attempt to make the invisible, visible. However, the literature demonstrates a lack of research, in particular, into the effectiveness of learning through structured role-play and the impact of this method on students using Multi-User Virtual Environments (MUVEs).

This paper exhibits the effects of an interactive role-play learning activity, supported within a MUVE, on the learning process. The activity is generated by a data-driven framework that acts as a template for the creation of the role-play the role-play is generated automatically from pre-defined data stored in a database. The framework is generalizable, which means that it can be used for other role-play subjects by re-configuring the data in the database. This paper aims to demonstrate the advantages of the 'immersion' that Virtual Reality (VR) can provide to its users via the means of allowing them to take on the role of an object involved in a message-passing system. This object will be one which is collaborative with other objects in a role-play activity. The role-play activity will be generated by a data-driven pedagogical framework called MMRP.

1 Introduction

1.1 Background

Most students lose focus at some point in the course of a long speech or lecture, and educators face the challenge of keeping their students' enthusiasm and attention on the subject. According to McConnell [1], it can be seen that the teacher's choice of learning activity has a huge impact on the students' understanding and engagement in the classroom. McConnell suggests minimizing the risks associated with adopting any given activity by keeping such activities short and well-structured.

There are several advantages to the use of simulation in an educational context. Firstly, it supports the learning-by-doing approach [2]. Secondly, it is a robust tool for enhancing the engagement of the students and for giving them a sense of control over the course of their experiments [3]. Finally, it provides the students with immediate feedback [4].

Presented at the 5th 'Immersive Learning Research Network Conference (iLRN'2019) held in the University of Westminster, London UK, June 23–27, 2019

Simulation can be used by educators as a method for explaining complex ideas across a range of disciplines. This leads us to a discussion of the main focus of our study - which is the use of role-play in education. Role-play is a form of simulation that can be used to encourage students to work collaboratively in order to solve issues which arise. For example, Colella [5] conducted an experiment using drama ('role-play' here indicates actual, physical actions and interactions undertaken via drama) to teach science and the use of technology. In this experiment, the students participated in a simulation, carried out in the real world, using small communication computers called Thinking Tags; these could be used to transform the students into participants in a large-scale micro-processor mediated world.

With newly available, advanced technologies, role-play can be used within Virtual Worlds (VWs); thus, students can be immersed in the learning process, and this can help them to become more engaged. There are several examples in the literature of role-play being deployed in a VW, such as those mentioned in the "Six Thinking Hats" framework description by Sue Gregory and Yvonne Masters [6] and in "Online Role Play Stories" by Mary Dracup [7]. However, generally there is a lack of research into generating role-play activities which are to take place as part of a structured learning design.

1.2 The Scope of the Paper

In light of the above, we introduce here the Mixed-Mode Role-Play (MMRP) framework [8] , which is a novel data-driven pedagogical framework for generating learning role-play activities that are based on passing messages between 'actors' in a virtual environment. One of the actors becomes, effectively, an avatar controlled by a human player (this is the humanized object) and the others are automated and supported by the system - hence 'mixed-mode'. The humanized object provides the student with the impression of being in the position of embodying their actions; this is one of the 3D environment's affordances [9].

The data used for rendering and generating the virtual environment's objects and their interactions for the role-play activity are read from an attached database. The environment and the activity are populated automatically in real-time and in relation to a selected scenario. In this present study, we claim that employing a data-driven approach supports the generality of our proposed framework. The data-driven approach employed in the MMRP framework provides it with generalization qualities. Indeed, this framework, for generating role-play activities, has three levels of generalization:

- <u>First level</u>: humanized object generalization.
  In many of the possible, generated role-play activities, the humanized object can be changed while the played scenario remains fixed (i.e., the student can play different roles in each of the generated activities).
- <u>Second level:</u> learning task generalization.
  This means that the scenario of a role-play can be changed in order to generate a number of different role-play activities with different learning objectives.

- Third level: subject generalization.
  The database is alterable, under specific guidelines, so that it can lead to the generation of role-play simulations other than the one (prototype simulation) related to networking, described in this paper.

In addition, of course, generated role-play activities which operate in virtual environments may lead to better learning. Enabling the student to imitate an object in a role-play message-passing activity, interacting with other objects in a virtual environment, could provide better learning and understanding in a more beneficial way than conventional approaches; this would be by enhancing students':

- Learning engagement
- Association with the role of the imitated object

In order to examine the feasibility of MMRP, the claimed generalization, and its learning effectiveness, three evaluation phases, each designed to validate one level of the claimed framework generalization were used; these are presented later.

However, in the first two sections of this paper, we emphasize the affordances of drama (role-play) from a theoretical point of view and the benefits of rendering it in a virtual environment.

2 A Theoretical View of Drama in Science Education

Role-play is defined as 'behaving in accordance with a specified function' in The Concise Oxford English Dictionary (1978 edition) [10] and is believed to be a powerful tool for learning. Its use in learning is often based on learners engaging mentally and physically in a trajectory activity, acting in interchangeable roles according to a scenario-script. Braund [11], in his research, points out that there is a lack of role-play activities taking place in science lessons, generally, and introduced his theoretical model for the use of drama in science education - which is based on Brook's 'empty space' theory of drama [12]. Braund's science-learning model defines drama in science education as a process of rationalizing between two worlds of knowing: the learner's world and the scientist's. This model has two levels whereby the ways in which different activities operate across the distance between the learner's world of knowledge and the scientific world of knowledge may be viewed. The first level is that of the general model, where the empty space between the two worlds is filled with learning activities which are placed there in order to reduce the amount of cognitive dissonance present and to close the gap between the two worlds. The second level, which is the focus of our research, shows how drama helps to fill the 'empty space' between these two worlds (**Fig. 1**). The researcher claims that his model can better support a 'constructivist approach' to learning which improves the student's engagement and interest in the subject matter.

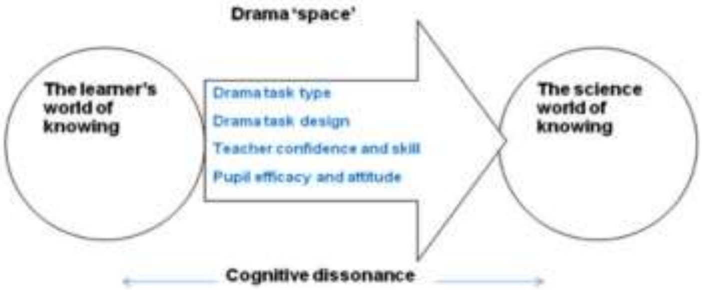

Fig. 1. A model for learning science through drama

3 Virtual Reality in Education

Virtual Reality (VR) refers to computer-created environments that simulate real environments, where the users of such an environment are represented by avatars and can interact with each other and with virtual objects [13]. Many studies and researchers have investigated the potential impacts of using VR in education. One of the affordances which has a special interest to us, is that it can foster an active environment, so increasing the students' engagement with the learning content.

However, seeing the lack of explicit guidelines concerning the use of VR as a tool in experimental learning, Jarmon et al. [14] carried out a study on 'how to utilize the 3D virtual world in an experimental project'. Using an example project, he was able to demonstrate the effectiveness of using such an environment in learning and this quite effectively encouraged educators to then use VR in experimental learning - as a 'playground' for learners.

From a theoretical point of view, Winn [15] identified that constructivist approaches often provide the best basis for creating educational applications using VR. Such an approach means that the learners will often boost their cognition and construct their learning through relating their reflections about the simulated objects in the virtual environment to previously learnt abstract concepts.

Mantovani [16] indicates that even if it is admitted that there is potential in using a virtual environment for educational experiments, it must also be recognized that there are further problems and challenges which need to be addressed. These can often be due to practical considerations such as the high cost of development, the lack of reference standards, and issues around usability and access. Educators, and designers of Multi-User Virtual Environments (MUVEs), should be aware of these challenges.

4 Role-play in Virtual Environments

As we discussed earlier, one of the fundamental benefits of using role-play in teaching and learning is to improve the student's engagement with the learning process which can increase their understanding of the subject. The realism and engagement represented by an educational game (N.B., a structured game is another term used to refer to role-play) can have an impact on learning outcomes, according to Tashiro and Dunlap's study [14]. Winn [11] added, in his study, that realism and engagement can be increased by conducting the role-play activity in a 3D VW; this is due to the immersive nature of such an environment. A virtual world can enhance the user's feelings of immersion, allowing them to build their knowledge from direct experience resulting from being a part of the virtual world. Moreover, a virtual world provides a platform from which to observe the participants and the overall activity, with the ability to record the outcomes.

In addition, a 3D VW can offer a richer experience for the users than a simple 2D Web application, often combining many features together in a single environment. These can include instant messaging within the group, voice chat, rich user profiles, and creative collaboration via online social interactions that involve sharing various objects and services within the virtual world [4].

VR can be used to support students to reach their desired learning outcomes through constructivist and problem-based learning. Alzahrani [17] presented, in his thesis, empirical evidence based on his experience that participants' performance was improved by using a VR platform - as compared to that achieved when using a 2D web-based platform.

Another significant advantage of 3D VWs is that these environments have shown great potential for collaborative learning [9, 18], via the use of Multi-User Virtual Environments (MUVEs). The collaborative features that are provided by a MUVE can be used to support group role-play activities.

This study explores the opportunities afforded by the use of virtual worlds for group role-play activities. It demonstrates an approach which can enhance overall learning effectiveness and creativity while reducing the costs and risks typically associated with these types of activities.

5 Framework Overview

With respect to the above, a computational pedagogical framework has been designed here, called MMRP (**Fig. 2.**), which was able to generate an effective role-play activity for use within a virtual environment. The actions dictated by this framework are

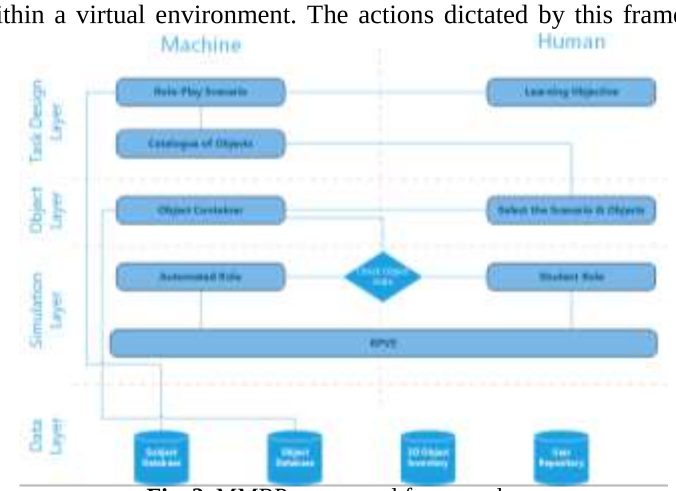

Fig. 2. MMRP conceptual framework

divided into those concerned with human factors and those concerned with machine factors; they operate interchangeably across three main layers [8].

MMRP is proposed as a mechanism for exploring the learning affordances of humanizing a technical object in a simulated system, within a RPVE. From a computer science point of view, MMRP is a data-driven model; the framework acts as a template which allows for the rendering of role-play activities and 3D objects within a VW automatically. It generates an interactive role-play simulation, and the processes of the simulation will change, in real-time, in a way which is dependent on the user input. The environment and its objects are created on the fly from data stored in and retrieved from the repository database. From a learning-theoretical point of view, MMRP is designed in a similar fashion to Brook's and Braund's models [11, 12]. In order to fill the gap between the two worlds, the learner's and the science's, immersion within the VE is used; the learner attempts to complete a role-play task triggered by a learning objective - collaboratively. We believe that the student enrolled in the generated role-play activity will be facilitated to fill their knowledge gap concerning the targeted subject.

With the intention of reusing the framework for other subjects which can be presented using message-passing scenarios, a standard data representation is mandatory for the structuring of the database. Moreover, CRC cards have been described by Beck and Cunningham[19] as a tool for teaching object-oriented thinking to programmers. However, Hvam and others [20] introduced a modified way of modeling a scenario with CRC cards. They added more fields to the structure of the CRC card in order to enhance the resultant role-plays. These additional fields were: aggregation, generalization, and knows/does. These additional fields help link objects which are from different classes. They are useful for tracing the roles of inheritance and 'has a' relations. This model not only enriches the environment's object population but also supports role tracking. In our model, the data is structured as CRC cards, each of which comprises class name, responsibilities, collaborator, aggregation, and knows/does (**Fig. 3.**). Then, the data is inserted into a database to be retrieved in order to create the OO class that will be used to render the 3D objects in the VE. The objects' names are the same as the class names used in the CRC cards. The responsibili-

Class name Application	ID 1	Type Main
Responsibilities Serves as the window for users and application processes to access network services.		
Aggregation		
Superparts:		
Subparts: HTTP FTP SMTP		
Knows/Does:		Collaborations
Knows		Transport
Does		
• Makes sure that the other party is identified and can be reached • Determines protocol and data syntax rules at the application level		

Fig. 3. Application layer CRC card as an example

ties defined are related to the protocols which can be used and the messages which can be passed. The collaborator is retrieved from the next object field. The additional fields assist in organizing the hierarchy and the relationships which exist between the objects.

6 Experimental Framework

The evaluation experiment was conducted as a proof-of-concept for the purpose of validating the study claims related to the MMRP generalization levels and the learning effectiveness of Mixed-Mode Role-Play in RPVEs. Two experimental phases were designed. First, one based on the Internet Protocol Suite (TCP/IP) layers; the (TCP/IP) layered networking scenario represents a typical learning scenario for Higher Education computing and networking students [8] (**Fig. 4.**). Another phase, the *Database phase (DB),* provided quite different activities; these were created around the topic of the acceptance of languages by *Finite State Machines (FSMs).*

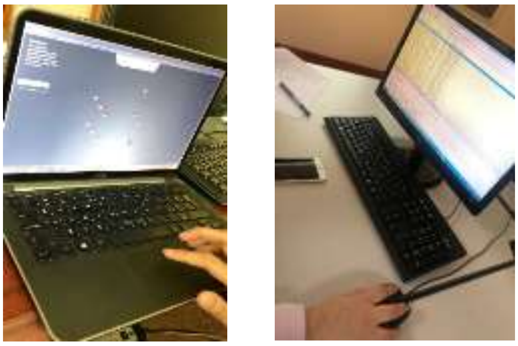

Fig. 4. Participants conducting the experiment

6.1 The Evaluation Measurements:

Validating the Fidelity of MMRP as a Pedagogical RPVE. MMRP generates role-play activities which act as visualization tools to assist in learning. In order to evaluate such learning tools we utilized the same evaluation technique that were used for the VirPlay3D2 evaluation [21] (a visualization tool for OO learning), with some additional criteria, as follows:

- User acceptance:
  - Does the user enjoy playing their role, interacting with the other objects?
  - Is the environment easy to use?
  - Is the access to information straightforward?
  - Does the user understand the environment's design?
  - Does the user understand the interactions between themselves and the environment's other objects, and between the other objects?
- The metaphors:
  - Does the user understand what each 3D object represents?

    - Does the interaction/message-passing between the objects give the user an idea of how the actual objects in the real world interact with each other?
- <u>The usefulness of the information represented in the role-play scenario</u>:
    - Are the descriptions of the role-play tasks and the environment's objects sufficient?
    - Are the system messages displayed on the screen adequate?
    - Is the message-passing represented on the screen sufficient for the understanding of the roles' processes?

Model Validation. As Sargent [22] states, the purpose of a simulation model must be referred to in order to determine its (the simulation's) validity. In the development phase, several questions were raised which were then answered in the testing of the model used here. The model's output variables provided the answers to these developmental questions. The accuracy of these outputs were in an acceptable range.

The parameters of the MMRP tests can be categorized as follows:

- Animation Validation: To validate the framework's operational behavior and the displaying of graphics while learning scenarios and tasks changed.
- Parameter Variability: To test the effectiveness of changing the input (the scenario, and the humanized object) on the outcomes while also changing the uploaded data.

Learning Gain and Student's Feedback. The participants were asked to take pre-tests and post-tests so that their learning gain could be measured. The outcomes of these tests and the collected data were analyzed and compared across the experimental groups. The post-test questions were predesigned in accordance with the module, 'Introduction to Computing', that the activity is designed around. After answering these questions, the participants were asked to analyze and comment on the roles that they had taken upon themselves in the simulation and the achievements that they had attained in relation to the tasks they had taken part in – so that they (the participants) could provide overall feedback, verbally.

Learning Engagement and Role Association Questionnaires. Wiebe [23] developed a new self-report instrument for user-engagement by extending the User Engagement Scale (UES) of O'Brien and Toms [24] to include user engagement in the context of game-based environments. Our platform implements a form of game-based simulation. Thus, we applied Wiebe's enhanced instrument in order to measure and analyse student engagement. There are four scalable factors: Focused Attention (FAz), Perceived Usability (PUz), Aesthetics (AEz), and Satisfaction (SAz). These factors were used in the construction of a questionnaire to be filled-in by every student after participation in the activity, based on their experience.

6.2 The Evaluation Phases

Network Learning Phases. The learning experiment phases took place at the University of Jeddah. This location was chosen because of the ease of access it afforded to the researcher, in terms of the required resources and the number of students available for participation in the experiment.

Thirty-six students participated in the network learning activities. All the participants were at their third level at the university, or higher. This made it almost certain that they had been introduced to the concepts of network layers and protocols. They were dived equally into groups: *Control Group (CG), Humanized Group (HG),* and *Scenario Group (SG).* After signing a confidential consent form, each participant took a pre-survey to confirm that they had the requisite knowledge concerning the subject of networks. Then, after they had completed the given learning tasks, they were required to take the post-test and respond to the evaluation measurement survey.

1. Conventional learning approach phase, CG

In this phase, the 12 participants engaged individually in the Wireshark [25] activity in order that the incoming/outgoing packets processed by their lab device could be captured. The students analyzed the captured packets messages and the protocols in each layer, based on a guide they received from the instructor (read more about Wireshark on wireshark wiki[26]).

2. MMRP phases

Network Virtual Environment. In a virtual environment, the network layers populate as 3D capsules. These represent the main objects of the learning scenario which interact with each other by passing messages. Every layer capsule is surrounded by boxes representing the protocols of that layer. There are four layer-capsules and the humanized object is represented by an avatar controlled by the user (**Fig. 5.**). The user is able to change the camera view; this brings greater fidelity to the 3D environment and results in a greater sense of presence. The views which can be referred to are the user's view, the entire environment's view, and the current object's view.

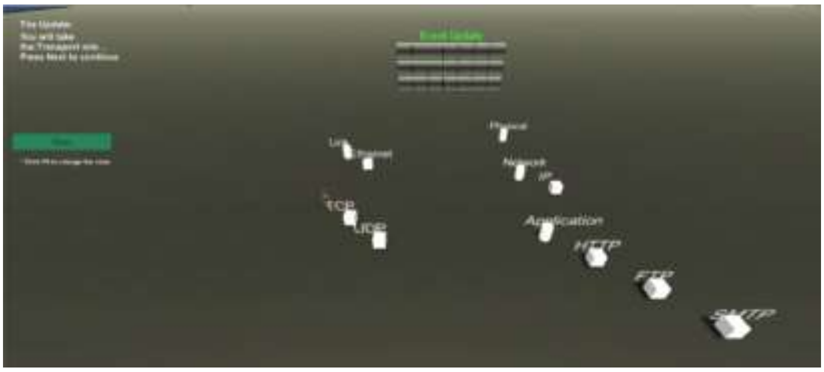

Fig. 5. The overall environment views

Network Learning Scenarios. In each scenario, the network layers interact with each other by passing messages in order to complete selected tasks (such as, to retrieve a web page from a server). The 3D environment's objects represent the network layers. The participants enrolled individually to take on the role of one of the layers (which then became the humanized object) and interact with the other layers (which remained automated by the system) to achieve a given task. The humanized object means the layer that the student is imitating. This is represented in the VE by an avatar, and the user controls this via their keyboard (**Fig. 6.**).

Fig. 6. The Humanized (Transport Layer) role

The user actions:

- Observe the other objects undertaking their roles.
- Receive the messages from the previous layer.
- Choose the correct protocol based on the received message.
- Deliver the message to the next object.

The return:

- Complete the role-play activity
- Achieve the learning objective.

It should be emphasized, however, that the data-driven architecture of the framework dictated that data for rendering the environment's object was not stored in the world a-priori. The environment and its objects were populated on the fly, which meant that different objects appeared with different scenarios. This process is what we believe shaped the generalization term that we are concerned with here.

The Unit of Learning. To plot the learning scenarios and the objects' roles within these scenarios, the role-play activity is rendered into interoperable Units of Learning (UoLs) in accordance with IMS Learning Design (IMS-LD), [27] (**Fig. 7.**).

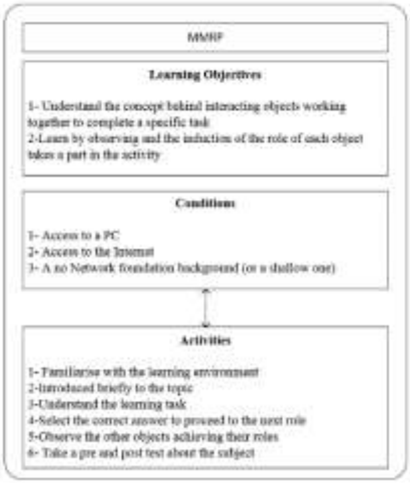

Fig. 7. Unit of Learning

The Experimental Groups

– <u>HG: Fixed scenario, varying humanized object</u>

Twelve undergraduate students participated, each individually, in three MMRP generated role-play activities. In addition to validating the first generalization level of MMRP, this phase purposed to evaluate the effectiveness, in terms of the student's learning, of changing the humanized object across three runs of the same scenario.

– <u>SG: Fixed humanized object, varying learning scenario</u>

The 12 students in this group each played, individually, the same humanized object role across three different scenarios; this was so that the second level of the framework generalization could be validated.

<u>3. DB phase, changing the database to represent a new subject</u>

As mentioned earlier, any course targeted for the employment of MMRP should contain role play scenarios wherein the objects of the scenario interact with each other by passing messages. To validate the framework's third level of generalization, subject generalization, another set of role-play activities was generated using the MMRP framework, this time focused on finite-state machine scenarios. Finite-state machines (FSM) represent a basic concept within Computational Theory that fits the requirements for use in these experiments. A FSM is any device which stores only its own state at a given time and can receive an input which causes a change to this state and/or an action or output to take place. There are only a finite number of states which such a machine can adopt. It is the lowest level of structure used in models of computation.

"A *finite-state machine* $M = (S, I, O, g, s_0)$ consists of a finite set S of *states*, a finite *input alphabet*, I, a finite *output alphabet*, O, a *transition function*, f that assigns to each state and input pair a new state, an *output function g* that assigns to each state and input pair, an output, and an initial state s_0" [28].

A FSM-related database was\created using the CRC card data organization presented earlier. Then, the data was retrieved to generate FSM-focused activities and this resulted in a FSM virtual environment as follows:

- The FSMs' various *States* are rendered as the environment's objects.
- The *Inputs* become the scenarios or the passing of messages between these objects.
- The *transition function f* is the responsibility of each object.
- The *Outputs* become the collaboration

7 Findings and Conclusions

The measurement factors used for the evaluation were designed mainly to measure the learning gain, the model validation, and the learner's engagement and acceptance.

Based on the pre-test results, 33.3% of the participants knew only the terminologies and the terms of the network layers and protocols and only 57 % of them could give brief description about the function of each layer and its protocols. The preliminary post-tests results regarding the students' achievements across the learning groups (*CG*, *HG* and *SG)* revealed that the MMRP groups were at an advantage compared to the conventional learning approach group (**Table 1**).

Group	Average Assessment Score
CG	37.46 %
HG	74.36 %
SG	55.5 %

Table 1. post-test results

Most of the participants in the MMRP groups' activities commented positively on their experience. One said 'They were beautiful and helpful activities that would help me not to forget the presented information while enjoying learning '. However, many of the participants recommended that the display design should be improved to make it more attractive. In addition, students' answers about the system acceptance measures showed a high level of acceptance, by these learners, of the virtual environment. Likewise, the user-engagement results demonstrated high levels of attention, perceived usability, aesthetics, and satisfaction.

The learning gain, the participants' feedback, and the questionnaire outcomes back-up the claimed affordances, in terms of learning, of rendering role-play scenarios in VR.

The FSM model is currently in the final stages of implementation. Its associated animations and its parameter variability are to be tested shortly. Although not complete as yet, the FSM model has validated that the framework can be used for subjects other than the one used for the prototype simulation.

The above are only preliminary results from the evaluation. A critical statistical analysis of the collected data will follow and be presented for publication.

In summary, the aim of the MMRP framework is to yield contributions to both the fields of pedagogy and of computer science. The experimental framework which has been presented here is designed to validate the claim that the data-driven approach - involving data streamed from a repository to create a virtual environment and roles - supports the generalization claims for the MMRP framework. Moreover, the generated Mixed-Mode Role-Play activity wherein some of the roles are played by human participants and some are operated automatically by the system serves as a novel pedagogical framework, enabling the student to be part of a virtual world simulation, so that they can become more immersed in the learning process. Replacing the network database with another subject database which has the same structure (CRC card structure) does not affect the functionality of the framework. It simply renders different objects which are related to the alternative database's subject matter.

For the computer science field, our novel framework provides an approach to the construction of an object container which acts as a template for generating the OO objects of a role-play scenario – i.e., a data driven architecture. CRC Cards used as a technique for creating Mixed-Mode Role-Play simulation for message-passing scenarios. In addition, the prototype is an adjustable and editable set-up in which the system architecture is designed as a distributed and isolated construction of subsystems.

8 References

1. McConnell, J.J., *Active learning and its use in computer science.* ACM SIGCSE Bulletin, 1996. **28**(SI): p. 52-54.
2. Anzai, Y. and H.A. Simon, *The theory of learning by doing.* Psychological review, 1979. **86**(2): p. 124.
3. Tashiro, J.S. and D. Dunlap. *The impact of realism on learning engagement in educational games*. in *Proceedings of the 2007 conference on Future Play*. 2007. ACM.
4. Boulos, M.N.K., L. Hetherington, and S. Wheeler, *Second Life: an overview of the potential of 3-D virtual worlds in medical and health education.* Health Information & Libraries Journal, 2007. **24**(4): p. 233-245.
5. Colella, V., *Participatory simulations: Building collaborative understanding through immersive dynamic modeling.* The journal of the Learning Sciences, 2000. **9**(4): p. 471-500.
6. Gregory, S. and Y. Masters, *Real thinking with virtual hats: A role-playing activity for pre-service teachers in Second Life.* Australasian Journal of Educational Technology, 2012. **28**(3): p. 420-440.
7. Dracup, M., *Online role play stories, engagement and learning in higher education*. 2011, Deakin University.
8. Jambi, E., M. Gardner, and V. Callaghan. *Supporting mixed-mode role-play activities in a virtual environment*. in *Computer Science and Electronic Engineering (CEEC), 2017*. 2017. IEEE.

9. Dalgarno, B. and M.J. Lee, *What are the learning affordances of 3-D virtual environments?* British Journal of Educational Technology, 2010. **41**(1): p. 10-32.

10. McSharry, G. and S. Jones, *Role-play in science teaching and learning.* School Science Review, 2000. **82**: p. 73-82.

11. Braund, M., *Drama and learning science: an empty space?* British Educational Research Journal, 2015. **41**(1): p. 102-121.

12. Brook, P., *The empty space: A book about the theatre: Deadly, holy, rough, immediate*. 1996: Simon and Schuster.

13. Bainbridge, W.S., *The scientific research potential of virtual worlds.* science, 2007. **317**(5837): p. 472-476.

14. Jarmon, L., et al., *Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life.* Computers & Education, 2009. **53**(1): p. 169-182.

15. Winn, W., *A conceptual basis for educational applications of virtual reality.* Technical Publication R-93-9, Human Interface Technology Laboratory of the Washington Technology Center, Seattle: University of Washington, 1993.

16. Mantovani, F., *12 VR Learning: Potential and Challenges for the Use of 3D Environments in Education and Training.* Towards cyberpsychology: mind, cognition, and society in the Internet age, 2001. **2**(207).

17. Alzahrani, A., *Towards the Development and Understanding of Collaborative Mixed-Reality Learning Spaces*. 2017, University of Essex.

18. Duncan, I., A. Miller, and S. Jiang, *A taxonomy of virtual worlds usage in education.* British Journal of Educational Technology, 2012. **43**(6): p. 949-964.

19. Beck, K. and W. Cunningham. *A laboratory for teaching object oriented thinking*. in *ACM Sigplan Notices*. 1989. ACM.

20. Hvam, L., J. Riis, and B.L. Hansen, *CRC cards for product modelling.* Computers in Industry, 2003. **50**(1): p. 57-70.

21. Jimenez-Diaz, G., P.A. Gonzalez-Calero, and M. Gomez-Albarran, *Role-play virtual worlds for teaching object-oriented design: the ViRPlay development experience.* Software: Practice and Experience, 2012. **42**(2): p. 235-253.

22. Sargent, R.G. *Verification and validation of simulation models*. in *Simulation Conference (WSC), Proceedings of the 2009 Winter*. 2009. IEEE.

23. Wiebe, E.N., et al., *Measuring engagement in video game-based environments: Investigation of the User Engagement Scale.* Computers in Human Behavior, 2014. **32**: p. 123-132.

24. O'Brien, H.L. and E.G. Toms, *Examining the generalizability of the User Engagement Scale (UES) in exploratory search.* Information Processing & Management, 2013. **49**(5): p. 1092-1107.

25. Combs, G. *Wireshark is 2.6.2*. 1998; Available from: https://www.wireshark.org/download.html.

26. *Wireshark Wiki*. 14/4/2017; the wiki site for the Wireshark network protocol analyzer]. Available from: https://wiki.wireshark.org/.

27. Burgos, D. *What is wrong with the IMS Learning Design specification? Constraints And Recommendations*. in *LWA*. 2010. Citeseer.

28. Rosen, K.H., *Discrete mathematics and its applications*. 2011: New York: McGraw-Hill.