

LB/TH/33/2025
TH5923

Ontology Driven Augmented Reality Environments for Neurodiverse Learning

W. B. T. Withanage

22/228841M

Faculty of Information Technology

University of Moratuwa

June 2025

Ontology Driven Augmented Reality Environments for Neurodiverse Learning

W. B. T. Withanage

22/228841M

Dissertation submitted to the Faculty of Information Technology, University of
Moratuwa, Sri Lanka for the partial fulfilment of the requirements of the Degree of
MSc in Artificial Intelligence

June 2025

Declaration

I declare that this dissertation does not incorporate, without acknowledgment, any material previously submitted for a Degree or a Diploma in any University and to the best of my knowledge and belief, it does not contain any material previously published or written by another person or myself except where due reference is made in the text. I also hereby give consent for my dissertation, if accepted, to be made available for photocopying and for interlibrary loans, and for the title and summary to be made available to outside organizations.

W. B. T. Withanage

Name of Student:

Signature of Student

Date- 26.06.2025

Supervised by-

Dr. Thushari Silva

Name of Supervisor(s)

Signature of Supervisor(s)

Date- 26.06.2025

Dedication

To all neurodiverse children, whose vivid capabilities light up the world in
extraordinary ways.

To their parents, whose unwavering love nurtures endless possibilities.

And to the educators, therapists, and innovators who believe in every child's potential
and strive to build a more inclusive, compassionate future.

Acknowledgement

I wish to express my profound gratitude and deep respect to my supervisor, Prof. Thushari Silva, whose unwavering guidance, insightful feedback, student-centered approach, understanding, and constant encouragement made this research possible. Your mentorship has not only shaped the course of this thesis but has also been instrumental in my growth as a researcher and learner. And I extend my heartfelt thanks to the academic and non-academic staff of the Department of Computational Mathematics, University of Moratuwa. Your support, expertise, and commitment to nurturing intellectual growth have been invaluable throughout this journey.

I am deeply grateful to my beloved husband and my family, my batchmates of MSc. AI batch 15, who stood beside me with patience, love, friendship and endless encouragement. Thank you for believing in me even during the most challenging moments. Your sacrifices, understanding, and unwavering faith provided the foundation upon which this work was built. Finally, I also extend my deepest respect to the researchers, educators, designers, and innovators who strive every day to create inclusive and accessible educational environments. Your efforts are lighting the path toward a more understanding, accepting, and equitable future.

Thank you very much!

W. B. T Withanage

Abstract

The goal of this research is to construct, design, and analyze the effectiveness of ONLEARN, an augmented reality (AR) platform designed to assist children with autism in the ages of three to eight years old. The research focuses on addressing the absence of adaptive individualized learning technologies tailored for neurodiverse learners as there are significant cognitive, sensory, and social differences within the autism spectrum. The technology of ONLEARN is built around a formally defined ontology developed in Protégé with important concepts including sensory features, and social communication skills hierarchy. The ontology was hosted in a Stardog semantic reasoning engine, which allows dynamic inferencing. Learning content personalization and extraction is done using SPARQL queries and interaction data gathered in real time from the users.

ONLEARN employed Unity with the UnityIIS semantic bridge to embed the AR child-friendly interface, thus ontological intelligence could easily integrate into it. Additionally, ONLEARN incorporated a 3D conversational agent powered by Convai to interact with children emotionally and during instructional activities. Expert analysis validated the ontology's complexity, the realization of the AR interface's design for autistic learners, and the pedagogical rationale behind the seamless content structuring.

The results show that ontology-driven reasoning enhances the degree of personalization and effectiveness of augmented reality educational interventions for children with neurodiversity. Further work will center on increasing the degree of sensory customization, incorporating functional communication training units, improving cultural adaptability, and developing integration with educational and clinical systems for wider practical deployment.

Keywords: Ontology-Driven Systems; Augmented Reality; Autism Spectrum Disorder; Semantic Reasoning; Stardog; SPARQL; Personalized Learning; Neurodiversity; Unity Development; Conversational AI; Adaptive Educational Technology

Table of Contents

CHAPTER 1 INTRODUCTION	1
1.1 Introduction	1
1.2 Background and Motivation.....	2
1.2.1. Ontological Approach.....	3
1.3 Aim and Objectives	3
1.4 The Solution	4
1.4.1 Users	4
1.4.2 The IPO Structure of the Research	4
1.5 System Architecture	7
1.6 Resource requirements	8
1.6.1 Software	8
1.7 Structure of the Dissertation.....	9
CHAPTER 2 ONTOLOGIES AND AR FOR NEURODIVERSE	
EDUCATION- ADVANCES AND CHALLENGES	10
2.1 Introduction	10
2.2 Autism Spectrum Disorder in Educational Contexts	11
2.2.1 Characteristics and Educational Implications.....	11
2.2.2 Current Educational Approaches and Their Limitations	12
2.3 Ontological Approaches to Knowledge Representation in Education	14
2.3.1 Foundations of Ontology Engineering	14
2.3.2 Educational Applications of Ontologies.....	15
2.4 Augmented Reality in Special Education.....	16
2.4.1 Fundamentals of Augmented Reality	16
2.4.2 AR Applications for Autism Education.....	18
2.4.3 Challenges in AR Implementation	19
2.5 Integration of Ontologies and AR for Personalized Learning.....	20
2.5.1 Theoretical Foundations for Integration	20
2.5.2 Existing Integrated Approaches.....	21
2.5.3 Technical Frameworks for Integration	24
2.6 Ethical and Practical Considerations.....	25
2.6.1 Ethical Dimensions of Technology for Autism	26
2.6.2 Implementation Challenges in Educational Settings	27

2.7 Research Gaps and Opportunities	28
2.8 Summary	29
CHAPTER 3 TECHNOLOGY ADAPTED FOR ‘ONLEARN’	31
3.1 Introduction	31
3.2 Overview of Technology Options for Personalized Learning	31
3.2.1 Artificial Intelligence and Machine Learning in Education	31
3.2.2 Rule-Based Systems and Expert Systems	32
3.2.3 Semantic Technologies and Ontologies	32
3.2.4 Augmented Reality for Interactive Learning	32
3.3 Justification for Ontology-Driven Augmented Reality	32
3.4 System Architecture	33
3.4.1 Ontology Development	33
3.4.2 Augmented Reality Environment	33
3.4.3 Middleware for Ontology-AR Integration	34
3.5 Implementation Process	34
3.5.1 Knowledge Acquisition and Ontology Design	34
CHAPTER 4 ‘ONLEARN’ FOR PERSONALIZED LEARNING	35
4.1 Introduction and Hypothesis	35
4.2 Conceptual Framework	35
4.2.1 Personalized Learning for ASD	36
4.2.2 Sensory Integration and Multimodal Learning	36
4.2.3 Ontological Knowledge Representation	37
4.3. Methodological Approach to System Development	37
4.3.1 Knowledge Acquisition and Ontology Development	37
4.3.2 AR Interface Design and Implementation	37
4.3.3 Integration of Ontology and AR Components	38
4.4 Summary	38
CHAPTER 5 THE DESIGN ANALYSIS OF ‘ONLEARN’	39
5.1 Introduction	39
5.2 System Architecture	39
5.2.1 Top-Level Architectural Design	39
5.2.2 Knowledge Base Layer	40
5.2.3 Reasoning Layer	42
5.2.4 AR Application Layer	43

5.2.5 User Interface Layer	44
5.3 Educational AR Games for Autism.....	44
5.3.1 Sequential Cubes	45
5.3.2 ONLEAEN Assistant- “Emily” for ASD Children, Parents and Therapists	46
5.4. Design Principles for Sequential Cubes and ONLEAEN Assistant “Emily” ...	49
5.4.1. Sequential Cubes	49
5.4.2. Designing the ONLEAEN Assistant- “Emily”	50
5.5 Summary	51
CHAPTER 6 IMPLEMENTATION OF ‘ONLEARN’	52
6.1 Introduction	52
6.2 Software and Hardware Requirements.....	52
6.2.1 Software Requirements.....	52
6.2.2 Hardware Requirements	52
6.3 Implementation of System Components	53
6.3.1 Knowledge Base Layer Implementation	53
6.3.2 Reasoning Layer Implementation.....	53
6.3.3 AR Application Layer Implementation	53
6.3.4 User Interface Layer Implementation.....	53
6.4 System Integration.....	53
6.5 Testing and Evaluation.....	54
6.6 Summary	55
CHAPTER 7 EVALUATION	56
7.1. Introduction	56
Evaluation Methodology	56
7.2. Evaluation by Experts	57
7.2.1. Expert Profiles	57
7.2.2. Strengths Identified.....	57
7.2.3 Interface Design and Usability	58
7.2.4. Recommendations for Enhancement	59
7.2.5. Comparative Analysis of Expert Perspectives.....	60
7.2.6. Divergent Emphases	61
7.2.7. Priority Areas for Future Development	62
7.3. Post Evaluation with Voluntary Participants	62
7.3.1. Demographics and Participant Profile	63

7.3.2. Survey Result Analysis.....	63
7.3.3 Overall Value and Recommendations	67
7.4. Summary	68
CHAPTER 8 CONCLUSION AND FURTHER WORK.....	70
8.1. Introduction	70
8.2. Analytical Reflection.....	71
8.3. Further Work	71
8.3.1 Enhanced Sensory Customization	72
8.3.2 Cross-Cultural and Linguistic Adaptation	72
8.3.3 Executive Function and Metacognitive Support	72
8.3.4 Functional Communication Training (FCT) Modules.....	72
8.3.5 Addressing Different Areas of ASD Spectrum	73
8.4. Summary	73
REFERENCES.....	74
APPENDICES.....	82
Appendix A:	82
Appendix B:	88
Appendix C:	95
Appendix D:	102
Participant 1- Evaluation Survey	102
Participant 2- Evaluation Survey	107
Participant 3- Evaluation Survey	112
Participant 4- Evaluation Survey	117
Participant 5- Evaluation Survey	122
Appendix E:.....	127
Appendix F:.....	129

List of Figures

Figure 1.1: ONLEARN- High Level Architecture.....	8
Figure 5.1: ONLEARN High level architecture	40
Figure 5.2: Domain Ontology for ONLEARN	41
Figure 5.3: Stardog Ontology repository as a graph database	41
Figure 5.4: Stardog reasoner- SPARQL queries	42
Figure 5.5: Sequential Cubes (Shapes identifier)	46
Figure 5.6: ONLEARN Assistant- Emily conversing with a neurodiverse child	47
Figure 5.7: ONLEARN Assistant- Emily guiding a parent	48
Figure 5.8: ONLEARN Assistant- Emily conversing with a therapist to plan activities for neurodiverse students	48
Figure 6.1: Middleware communication flow	54
Figure 7.1: ONLEARN usability and user engagement	64
Figure 7.2: Feedback on Conversational Agent 'Emily'	65
Figure 7.3: Cognitive and Behavioral Outcomes from ONLEARN App	66
Figure 7.4: Participant Suggestions for AI Personalization Features.....	67
Figure 7.5: Relationship Between Key Survey Responses.....	67

List of Tables

Table 2.1.Comparative Analysis of Existing Systems with Ontological and/or AR Components for Special Education.....	21
Table 5.1: SWIRL rules assigned.....	43
Table 6.1: Test Cases.....	55
Table 7.1: Expert Background.....	57
Table 7.2:Assesing the framework.....	58
Table 7.3: Design and usability assesment.....	59
Table 7.4: Recommendations.....	60
Table 7.5: Comparative analysis on key points.....	61
Table 7.6: Expert focus areas	61
Table 7.7: Future development priorities.....	62
Table 7.8: Summary of the post evaluation results.....	68