THE DEVELOPMENT OF A MODULAR FRAMEWORK FOR SERIOUS GAMES AND THE INTERNET OF THINGS

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ABSTRACT

The combination of Serious Games and the Internet of Things is a recent academic domain of research. By combining the software and gaming advantages of Serious Games with the interconnected hardware and middleware driven ecosystem of the Internet of Things, it is possible to develop data-driven games that source data from the local or extended physical environment to progress in the virtual environment of gaming.

The following thesis presents research into Serious Games and the Internet of Things, focusing on the development of a modular framework that represents the combination of the two technologies. Current research in the domain of Smart Serious Games omits a modular framework that is application independent and outlines the software and hardware interaction between Serious Games and the Internet of Things, therefore this thesis is the first to introduce one. By developing such a framework, this thesis contributes to the academic domain and encourages new and innovative real-world applications of Smart Serious Games that include healthcare, education, simulation and others. Further to the framework, this thesis presents a survey into the network topologies for Serious Games and the Internet of Things and a computer algorithm that provides a measure of student engagement, integrated into a Smart Serious Game developed as part of the undertaken research named Student Engagement Application (SEA).

This thesis utilises a semester-long experiment and the techniques of control groups and randomised controlled trials to investigate and compare the measures of engagement obtained through SEA and self-reflection questionnaires, and the measure of student engagement against academic performance, respectively. After statistical analysis, the data presented strong confidence in the measure of engagement through SEA, validating the effectiveness of the proposed framework for Smart Serious Games.

ACKNOWLEDGEMENT

This thesis was completed following extensive research into Serious Games, the Internet of Things, and Student Engagement, and I would like to take this opportunity to express my gratitude to those who supported me through this journey.

Special thanks go to my Director of Studies, Dr Stephen Tang, whose commitment, patience and expert knowledge aided the research project and myself as a researcher and was fundamental in the completion of this research project. I am also grateful to Dr Martin Hanneghan and Dr Chris Carter for their invaluable insights into research and game development respectively. I would like to thank Liverpool John Moores University and in particular the Executive Dean of the Faculty of Engineering and Technology, Prof Ahmed Al-Shamma'a for funding this project and providing me with the opportunity to complete this research.

I am thankful to the HR of the Department for their continued support through this journey, and for the additional funding of conferences that helped pave the way for this research project.

Most importantly, extended thanks go to my wife Rebecca Henry, and my mother and father in law, Adele Henry and Andrew Henry, for their unwavering support, no matter the challenge I set myself. They say behind every successful man is a strong woman, I am lucky to be supported not only by her but her parents too.

Finally, I would like to dedicate this work to my son, Jack Henry, for the motivation he provides me to achieve.

DECLARATION

I hereby declare that the work presented in this thesis has been individually completed by myself at Liverpool John Moores University, with the guidance and expert input from the individuals acknowledged and has not been submitted for any other degree. A list of research publications (see List of Publications) were produced during this research study and some of those are presented in the context of this thesis where deemed necessary.

J. Henry

John Melphon Henry

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LIST OF PUBLICATIONS AND AWARDS

Journals

1) **J. Melthis,** S. Tang, P. Yang, M. Hanneghan, C. Carter, (2016), "*Topologies for combining the Internet of Things and Serious Games*", Journal of Intelligent and Fuzzy Systems, 31(5), pp. 2685 – 2696.

Conferences

1) **J. Henry,** S. Tang, M. Hanneghan, C. Carter, (2017), *"A Measure of Student Engagement for Serious Games and IoT"*, 11th International Conference on Technologies for E-Learning and Digital Entertainment (Edutainment 2017): E-Learning and Games, Bournemouth, pp. 262 – 270.

2) **J. Henry,** S. Tang, M. Hanneghan, C. Carter, (2018), *"A Framework for the Integration of Serious Games and the Internet of Things (IoT)"*, IEEE 6th International Conference on Serious Games and Applications for Health (SeGAH 2018), Vienna.

Awards

Best Poster Award, **J. Henry,** S. Tang, M. Hanneghan, C. Carter, (2018), *"A Framework for the Integration of Serious Games and the Internet of Things (IoT)"*, IEEE 6th International Conference on Serious Games and Applications for Health (SeGAH 2018), Vienna.

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CHAPTER 1 – INTRODUCTION

1.1 Thesis Introduction

This thesis investigates the combination of the Internet of Things and in particular interconnected sensor devices and data from the physical environment, with Games, specifically Serious Games. The term Serious Games describes computer games built for non-entertainment domains (Michael & Chen 2005; Tang et al. 2013). Serious Games are games with 'serious' goals including education and behavioural modification with emphasis on reaching an end goal through user interaction. Internet of Things (IoT) accounts for an ecosystem comprising of interconnected devices, middleware and users that operate in Smart Environments (Atzori et al. 2010; Khalid et al. 2014).

The integration of Serious Games and the Internet of Things is a research topic that is increasingly attracting attention from the academic community. Literature on the topic is expanding, with investigations into the integration itself (Favorskaya et al. 2015), frameworks (Kim 2017) and proposed applications (Konstantinidis 2017; Garcia-Garcia et al. 2017). The term Smart Serious Games (SSGs) (Favorskaya et al. 2015), is used to define the integration of Serious Games and the Internet of Things. Since the term is appearing more frequently as it increases in popularity in academia, this thesis will continue to utilise this terminology to describe the technologies.

This thesis develops an application neutral framework for combining the Internet of Things and Serious Games. By introducing such a framework, this thesis provides the foundations of interconnection between the two technologies and accelerates the development of such a solution in the field. The application neutral nature of the proposed framework increases its impact by extending its potential scope away from this thesis' case study and to potential applications such as healthcare, rehabilitation, education and immersive games that utilise interconnected devices.

For validating the proposed framework, this thesis utilises the case study of measuring student engagement through a Smart Serious Game that accounts for data obtained from the local environment by utilising the Internet of Things to overlay a measure of behavioural engagement onto self-reflection instruments. The engagement theory relates to a vast setting type, including employee engagement, student engagement and others. Research into the impact of engagement on employees identifies a correlation between performance and engagement (Rich et al. 2010; J. 2014). This fact remains true when investigating the correlation between student engagement and student performance (Skinner & Belmont 1993). Furthermore, a measure of student engagement provides an indication of student dropout, as research proves an affiliation between the two (Appleton et al. 2006; Finn 1989). Therefore, the obtained measures of Student Engagement are statistically validated by correlating against student academic performance.

1.2 Problem Statement

Current research surrounding Serious Games and the Internet of Things proposes terminology (Smart Serious Games), applications, or states it as future extensions to projects. This thesis' extensive literature review discovered the following problems with existing research into Serious Games and the Internet of Things:

- All literature into Smart Serious Games defines service-specific game architectures or frameworks that limit the scope of application and place a hurdle when developing a Smart Serious Game of any application (Konstantinidis 2017; Garcia-Garcia et al. 2017; Kim 2017).

- No literature surveys the topological requirements of Smart Serious Games and presents topologies for the academic domain.

Due to the gap in the current literature, challenges arise when attempting the development of a Smart Serious Game including:

- How to integrate the technologies and effectively develop a Smart Serious Game of any application.
- How to develop a Smart Serious Game that utilises data from the physical environment to affect gameplay in an informative manner, and how the data interacts in such a scenario.

This thesis solves the stated problems by defining an application neutral, modular and interconnected framework that provides the foundation for the combination of Games, Serious Games, Gamification or Edutainment with the Internet of Things as Serious Games share attributes with these types of games expanding the scope of application of the framework proposed in this thesis. Additionally, this research project surveys the network topologies applicable to Smart Serious Games and recommends topologies for different applications within the scope of research.

1.3 Aims and Objectives

This thesis aims to develop a modular framework that presents the interconnection of Serious Games and the Internet of Things. This proposed framework will illustrate the theoretical relationship between the two technologies from an application neutral perspective, meaning future research of any application that combines games with interconnected sensors will benefit from this thesis.

Accounting for the research aims, this project will test the following hypotheses:

- A framework can modularly outline the interconnection between Serious Games and the Internet of Things (SSGs).
- The proposed framework can produce a Smart Serious Game that measures student engagement.
- Computer algorithms can measure student engagement, using the Internet of Things technologies and Serious Games.

To meet the stated aim, this thesis includes the following objectives:

- Develop a modular framework for Serious Games and the Internet of Things.
- Develop a Smart Serious Game that measures student engagement to validate the proposed framework.
- Develop a data algorithm that measures student engagement that incorporates students' self-reflection, and habits and events in the physical environment.

Based on these hypotheses, the following tasks have been set:

- Evaluate framework against current solutions for Smart Serious Games and define the scope of application for the proposed framework.
- Design and develop a Smart Serious Game prototype that monitors student engagement and provides feedback to students.
- Conduct a three-month experiment, to evaluate the effectiveness of the produced prototype.

Based on the presented tasks, this thesis produces the following deliverables:

- A Smart Serious Game that measures student engagement.
- Document findings and disseminate them in journal and/or conference publications.

By meeting this thesis aim and completing the outlined objectives, the research project will come to a successful conclusion, with a positive impact on the relevant scientific discipline.

1.4 Contributions and Novelties

This thesis presents a multi-discipline research project that combines the ecosystem of the Internet of Things with Serious Games. Furthermore, this thesis investigates the benefits of utilising Serious Games and Internet of Things technology for measuring Student Engagement. The main novelty of this thesis is the modular and interconnected framework for combining Serious Games and the Internet of Things. This is a novel contribution, as Chapter 2 presents the void in existing research that this project aims to fill. Additionally, this thesis describes the importance of filling the defined void below with a list of contributions including:

- **A modular and interconnected framework combining the Internet of Things and Serious Games for the development of Smart Serious Games:** This framework forms the foundation for academic and industry-led projects that wish to replicate or contribute to the domain of Smart Serious Games. The framework maintains application neutrality and focuses on the relationship of the technologies required for combining Serious Games and the Internet of Things.
- **A computer algorithm that measures student engagement by incorporating self-reflection scores:** Section 1.1 discusses the importance engagement portrays within academia and industry. Student engagement is a powerful indicator of student

academic performance and potential student dropout (Appleton et al. 2006; Finn 1989)

- . Student engagement is conventionally measured through self-reflection instruments (Appleton et al. 2006; Coller & Shernoff 2009; Handlesman et al. 2005; Skinner & Belmont 1993; Brockmyer et al. 2009). With the emergence of the Internet of Things and the domain of Smart Serious Games, an opportunity arises to challenge the conventional measure of student engagement and investigate if self-reflection alone provides a better measure than a combined measure that accounts for the student's actions in the physical world.
- **Topologies for combining the Internet of Things and Serious Games:** Existing literature details topologies or network architectures for online games of any domain (serious or not) and for topologies for the Internet of Things. This thesis provides the topologies that are suitable for Smart Serious Games based on their nature and the network requirements of Smart Serious Games.

1.5 Thesis Overview

This thesis is presented in eight chapters and three appendixes. Chapter 1 presented the scope of the research relevant to this thesis and defined the methodology used to investigate the combination of Serious Games and the Internet of Things, based on stated hypotheses. Furthermore, it specifies the contributions of this thesis and outlines their impact.

Chapter 2 provides the extensive literature survey for this thesis. It defines Serious Games, Gamification and the Internet of Things, alongside Serious Games and Student Engagement, to provide background to this thesis' findings and justify the course of research. Furthermore, the networking and data elements of the Internet of Things are discussed, and Smart Serious Games are presented, in accordance with the latest research in the academic field.

Chapter 3 investigates the networking topologies that are compatible with the development of Smart Serious Games, considering potential applications for each topology and stating the requirements relevant topologies must adhere to.

Chapter 4 presents the modular, interconnected framework for combining Serious Games and the Internet of Things, and describes the modules required and how they interact from a hierarchical perspective. This chapter also explains the requirements that future frameworks must adhere to for this domain.

Chapter 5 outlines the case study utilised to validate the framework presented in Chapter 4. This thesis utilises the measure of student engagement from a Smart Serious Game that integrates self-reflection tools with the help of data algorithms. Furthermore, this chapter presents how data persona was simulated during the development of the Smart Serious Game and justifies omitting Dynamic Difficulty Adjustment algorithms from the solution.

Chapter 6 describes the development process and justifies the choices made based on scientific research. The multi-element system is detailed from a programming and user interface perspective where appropriate.

Chapter 7 evaluates the data obtained from a semester-long experiment, using control groups to measure student engagement with conventional methods and with the developed solution respectively. Statistical data analysis is performed using techniques such as R and data triangulation to validate the framework and investigate if the hypotheses of this thesis were met.

Chapter 8 concludes this thesis and details the research limitations along with the technical challenges faced. This chapter also presents the suggested future works that arise from this thesis.

Appendix 1 presents the spreadsheet used for simulating data persona when developing the Smart Serious Game and defining the data algorithms.

Appendix 2 includes the questionnaire used in-game and as an electronic questionnaire that sourced a measure of student engagement.

Appendix 3 outlines the questionnaire developed for obtaining qualitative feedback surrounding the measures of engagement obtained through the period of experimentation. This questionnaire sourced the data required to perform data triangulation.

CHAPTER 2 – BACKGROUND

2.1 Introduction

This chapter initiates with a systematic review of current literature from an Internet of Things layer-based perspective, as shown in Figure .1. The extensive systematic literature review of Serious Games and the Internet of Things examined relevant articles from major academic databases, (IEEE Xplore, ACM, Springer digital library and Science-Direct). Core search terms include the keywords Internet of Things, Serious Games, Internet of Things Game and a wide range of other technologies. The results indicate that both topics of the Internet of Things and Serious Games are widely popular in literature, but there are few studies on the integration of Serious Games and the Internet of Things. It is worth exploring potential research issues in this area.

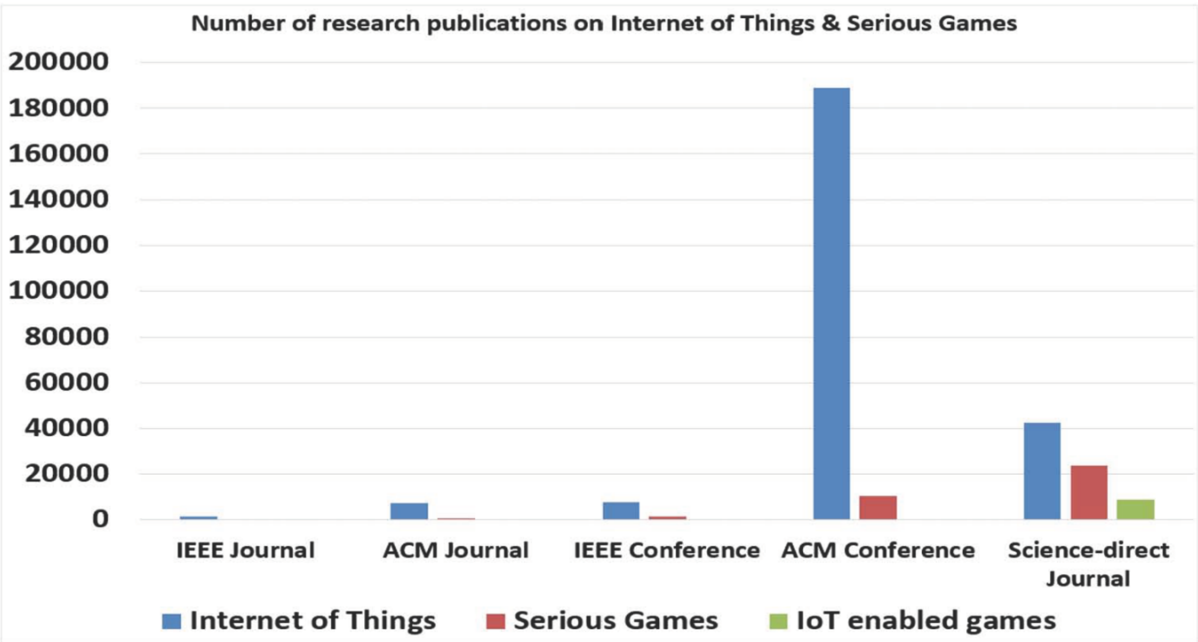

Figure 1.1 Number of Journal and Conference articles related to the Internet of Things and Serious Games from 2000 to 2015 (Internet of Things-Internet of Things, Serious Games, Internet of Things enabled Games)

This chapter presents high impact research on Serious Games and Gamification in addition to the latest academic developments and introduces the Internet of Things as an ecosystem based on notable research and the term of Smart Serious games. This chapter also includes research into data analytics, performed by data algorithms, and states the importance of their role when integrating Serious Games and the Internet of Things.

2.2 Serious Games and Gamification

Serious Games have been defined as computer games or games, not built primarily for enjoyment or fun (Michael & Chen 2005), or built for non-entertainment domains (Tang et al. 2013). Serious Games comprise of game characteristics with 'serious' goals including with emphasis on reaching an end goal through user interaction.

Modern computer games, and serious games, of all genres, utilise game engines for their development, to decrease development costs and time. Game engine is the term applied to an extensible software library which promotes game development without significant modification (Gregory 2014). Notable game engines include the Unreal Engine (commonly used for its extensive tools and features), DICEs Frostbite Engine (widely utilised for Electronic Arts games such as Battlefield), Microsoft's XNA Game Studio (utilised for the development of Xbox and PC games through C# and Visual Studio) and Unity (primarily known for its ease of use and cross-platform game deployment) (Gregory 2014). A game engine could be essential to develop and deploy a Serious Game that connects with the Internet of Things, dependant on the assets and virtual environment.

2.2.1 Serious Games Applications

Serious Games have a presence in a range of industry and academic applications including health (Burke et al. 2009; Baranowski et al. 2011), advertisement, training, education (Hamari et al. 2016), science and research (Tang et al. 2013; Zyda 2005). By harnessing the power of entertainment from gaming, serious games and gamification have provided a number of research and industrial solutions (Girard et al. 2013; Aldrich 2009). This thesis discusses related applications of Serious Games found in this literature survey below.

This literature survey found limited previous research into measuring student engagement (Coller & Shernoff 2009); instead, current research focuses on serious games and learning, where engagement with the game will increase the quality of learning (Shute et al. 2009), or simply measurement of engagement with an educational game (L. A. Annetta et al. 2009; L. Annetta et al. 2009).

Research into the use of Serious Games for optimising engagement with stroke rehabilitation by Burke et al. (2009), discovered a set of game design principles and a positive impact on patient engagement with the Serious Games tailored therapy in comparison to conventional therapy. A literature survey investigating the effectiveness of Serious Games as an educational tool by Girard et al. (2013), suggested Serious Games can be a powerful method for learning. Their research highlights the positive impact Serious Games possess in education.

Serious Games may be adapted into pervasive games to include the Internet of Things. Computer games played through converging physical and virtual worlds by utilising receptive technology can be defined as pervasive games (Laine & Sedano 2015). Commonly, pervasive games utilise Augmented Reality (AR), to bridge virtual and physical worlds and increase user impressionability (Lv et al. 2015). Serious games for healthcare utilise wireless networks to aid in rehabilitation and promote fitness, amongst other research topics. The aforementioned research displays the positive impact of Serious Games in healthcare and provides an insight into integrating hardware and physical environments with Serious Games.

2.2.2 Serious Games Engagement and Student Engagement

Student Engagement is a multifaceted theory that constitutes three key factors; behavioural, emotional and cognitive engagement, as described in the research review conducted by J Fredricks et al. (2004). Behavioural engagement relates to positive in-class conduct, involvement in learning (effort, concentration, contribution to class), and participation in activities (competitions, membership). Emotional engagement describes the feelings of students such as interest, anxiety, boredom and others. Finally, cognitive engagement focuses on the desire to complete extra-curricular activities and tasks, and the demonstration of strategic and methodical approaches to learning.

Research by J. Appleton et.al. (2006) outlines four subtypes of engagement: academic, behavioural, cognitive and psychological. Student engagement can be intrinsically or extrinsically triggered (Fredricks et al. 2004; Eccles & Wigfield 2002). Intrinsic engagement stems from the engagement of following an instruction for the activity itself whereas extrinsic engagement relates to the desire to achieve goals and objectives related to an activity.

All included research into student engagement provides the psychological measures needed to monitor and evaluate engagement. All research recognises the existence of behavioural, emotional and cognitive engagement. Therefore, the algorithm and game will include these aspects of student engagement in their measurements.

The student engagement theory is utilised for analysing dropouts in schools (Appleton et al. 2006; Finn 1989), where low engagement levels link to a higher dropout rate. This thesis uses Student Engagement as a case for combining Serious Games and the Internet of Things as the Department of Computer Science at Liverpool John Moores University recorded a dropout rate of 26.11% for the academic year of 2015-2016 and a rate of 25.98% for the academic year of 2016-2017. Theorising that Computing Departments across all universities in the UK

(N=107)[1] face similar difficulties, a strong measure of student engagement could collectively save universities £72,225,000 by reducing student dropout, based on the current tuition annual fees of £9,000 and an average intake of three hundred students[2]. The high dropout rate in the Department could relate to low levels of student engagement, therefore testing a measure of student engagement on this student cohort may produce an insight into the students within the Department whilst progressing the academic field of Smart Serious Games.

Student engagement is understood to be the involvement of people in an activity rather than the intensity of interaction (Appleton et al. 2006). Engaged students select tasks and learning objectives at the border of their comprehension and adopt a positive and optimistic approach to learning (Skinner & Belmont 1993). E. Skinner and M. Belmont (1993) outlined a psychological model, which drew a correlation between the competencies of students and their levels of engagement. Furthermore, their research identified a correlation between positive academic grade performance and student engagement. R. Carini et al. (2006) supported this statement in the review of Student Engagement and Student Learning, which identified a positive link between the two. This thesis will reverse this process and utilise student grade performance to validate the measure of student engagement received from Smart Serious Games.

Student engagement is usually measured through surveys based on self, and/or academic self-reflection (Appleton et al. 2006; Coller & Shernoff 2009; Handlesman et al. 2005; Skinner & Belmont 1993; Brockmyer et al. 2009). M. Handlesman et al. (2005), created a questionnaire in an attempt to measure course engagement based on a four-factor dimension. The four

[1] The Complete University Guide: https://www.thecompleteuniversityguide.co.uk/league-tables/rankings?s=Computer+Science visited 26/02/2018.
[2] University of Oxford: https://public.tableau.com/views/UoO_UG_Admissions/Courses?%3Aembed=y&%3Adisplay_count=yes&%3AshowTabs=y&%3AshowVizHome=no visited 26/02/2018.

factors comprised of *skills*, *emotion*, *participation and interest*, and *performance*. After performing validation tests against student grades, they discovered correlations between engagement factors and grades, however, due to the sample size acquired, their research could only provide an indication towards the questionnaire's effectiveness.

J. Appleton et al. (2006) measured student engagement using a questionnaire named Student Engagement Instrument, which was developed from a survey into relevant literature. The Student Engagement Instrument contained 56 items used for measuring cognitive engagement and psychological engagement.

A survey into serious games for education by C. Girard et al. (2013) highlighted an issue of obtaining quantitative data in Serious Games research, to generate meaningful results. Only 27% of studies showed an improvement in learning. By incorporating the Internet of Things with Serious Games, interconnected sensors become a source of quantitative data, adding a new dimension to data, and straying from the sole use of qualitative data. Another survey by T.M. Connolly et al. (2010) that investigated the positive effects of Serious Games for a variety of applications concluded that games have a positive effect on learning and motivation, however, the authors noted a need for more Randomised Controlled Trial based experiments to better understand the effects of Serious Games.

2.2.3 Engagement in Games

The following validates the use of game technology in this thesis for measuring Student Engagement. Literature investigating Serious Games and Student Engagement has presented a link between playing games and an increase in student engagement (Garris et al. 2002; Domínguez et al. 2013; Guillén-Nieto & Aleson-Carbonell 2012).

An empirical study by Hamari et al. (2016) investigated the use of Serious Games for engaging students in game-based learning environments. The result of their study indicated an increase in engagement levels whilst students were playing the game and increased learning through engagement and appropriate challenge, supporting Csikszentmihalyi's theory of flow (Csikszentmihalyi 1991). Hamari et al., indicate promise for utilising games as a means of measuring student engagement.

Scientific research has proven games are engaging and immersive. In detail, research by R. Garris et al. (2002), focuses on instructional games and their engagement with learners to accomplish better learning outcomes. Their suggested Input-Process-Output Game Model details an iterative Game Cycle that comprises of User Judgement, User Behaviour and System Feedback, and encourages interacting with a game. This game cycle remains true for a Smart Serious Game that measures student engagement.

The key difference lies in the mechanisms used to implement such an iterative cycle. User Behaviour and Judgement can now be monitored and inputted into the game through the use of network distributed sensors rather than direct user input. Additionally, predictive algorithms and machine learning add another layer of information that can aid in understanding engagement from external factors, such as traffic or weather conditions, like never before.

Research into the gamification of learning experiences by A. Domínguez et al. (2013), presented a solution focused on cognitive, social and emotional engagement, in an attempt to improve learning outcomes. Their research provided an indication of a measure of emotional and social engagement on students; however, they noted no significant improvement on learning outcome. Their research strengthens the case for measuring student engagement with game technology and the Internet of Things.

Research by V. Guillen-Nieto and Aleson-Carbonell (2012), acknowledged that serious games can generate engagement and stimulation in educational environments, but focused on the effectiveness of serious games for learning. Their empirical findings indicated that serious games are effective as learning tools, provided that the developed solution includes classroom procedures, and clearly outlines learning objectives as well as game cycle and game dimensions. The structure of the serious game V. Guillen-Nieto and Aleson-Carbonell (2012) developed provides a useful insight into game elements that must be included in effective serious games for educational settings. This thesis does not propose a Smart Serious Game for learning; however, as the game is based in an educational setting it will contain a user base of higher education students.

Research conducted by Coller and Shernoff (2009) did perform a measure of overall student engagement, alongside monitoring the effectiveness of learning through a serious game. Their preliminary results displayed an overall higher student engagement for students who utilised serious games for learning over traditional class delivery and homework. The scores for engagement were based on students' self-reflection. The proposed Smart Serious Game does not educate, but rewards good practice, focusing on the measure of student engagement.

Boyle et al. (2012), carried out a review of available literature into the principles for developing engaging games. Their findings uncovered that multiple factors affect engagement in games and games positively engage players when a game presents a balanced challenge. This thesis will provide a systematic point allocation based on an aggregate of sensor data and self-reflective scores. This approach rewards positive student engagement and follows the principles of flow (Csikszentmihalyi 1991).

V. Riemer and C. Schrader (2016) investigated the impact of behavioural engagement and self-monitoring on mental models through Serious Games and discovered the necessity for self-monitoring in Serious Games of such nature. Their research measured self-monitoring in game. V. Riemer and C. Schrader (2015) also researched the behavioural measurements for learning through serious games, in an attempt to bridge the gap in research surrounding the area. Their research found a difference in attitudes based on the serious game type, for example, simulation, and the gender that played the game, however, positive attitude was generated through play for learning. This thesis adopts this view and integrates self-monitoring into Smart Serious Games as a means of representing the conventional instruments for measuring Student Engagement.

This thesis does not suggest a replacement for measuring student engagement, but rather an overlay using game technology and the Internet of Things. Section 5.5 provides further information on this.

2.2.4 Gamification

An alternative to Serious Games, Gamification, is the process of improving services and/or products with the use of game elements for enhanced user immersion and behaviour (Blohm & Leimeister 2013). Deterding et al. (2011), surveyed the literature on game elements and serious games to propose a distinction and definition for Gamification. To their findings, gamification is the use of game elements outside a game context. Research into gamification and behavioural change (Blohm & Leimeister 2013), proposes engaging participants in an industrial setting. Research by Crowley et al. (2012) investigates the use of citizen sensing and gamification, for reporting issues in players' local environment. Their research outlines a framework for this integration and presents an example of relevant research into combining the physical world with game technology.

Based on these findings, this thesis does not integrate gamification and the Internet of Things, as the suggested solution contains game mechanics and is a standalone game with game rules, therefore containing the game elements within a game context. The proposed solution is also a Serious Game, as it is primarily developed for a 'serious' purpose.

2.3 The Internet of Things

The term Internet of Things (IoT) was firstly introduced by Kevin Ashton (2009) in 1999, aiming at identifying unique objects and their virtual representations in an Internet-like structure. Internet of Things describes interconnected devices or Things that operate in Smart Environments and communicate with virtual identities and/or personalities. Smart Environments can be defined as those where objects enhance comfort and ease task completion through their intelligence (Atzori et al. 2010). In addition, the Internet of Things accounts for an ecosystem, which is comprised of middleware (Khalid et al. 2014), users and interconnected devices.

The Internet of Things promises a future of interconnectivity between heterogeneous devices and data services. This interconnectivity will allow for better analysis of data-driven applications and prospects new software solutions that could not have been achieved without the Internet of Things (Atzori et al. 2010). Through the development of sensing technology, more things can be connected and labelled on the internet. The scope of the Internet of Things extends to people-to-things, things-to-things, and machine-to-machine amongst others. To elaborate, the Internet of Things enables the connectivity of anything at any time to any place. Research into the future of the Internet of Things by Kortuem et al. (2010), described the transition from the Internet to the Internet of Things, utilising the term ‘smart objects’ for interconnected devices with machine-to-machine intercommunication. Their vision materialised, with a large number of commercial devices that intercommunicate available to purchase for home use. Thus, it is appropriate to investigate the integration of Serious Games and the Internet of Things, whilst the Internet of Things increases in popularity and availability.

A survey by Atzori et al. (2010) categorises Internet of Things enabled technologies, in a four-layered Internet of Things architecture with a sensing layer, networking layer, data processing layer, and application layer. Each layer of this Internet of Things architecture is concerned with a wide board of technologies as itemised below:

- Sensing layer: Integrated with existing sensory devices (RFID, actuators, wearable devices, mobile phone, barcode, and others) to sense and collect the physical data from the real world (Wu et al. 2013).
- Networking layer: Provides basic networking and data communication over a wireless or wired network, including WWAN, WPAN, WLAN (Guinard et al. 2010).
- Data processing layer: Concerns a number of processing steps for handling raw sensory data (Xu et al. 2014), including the construction of data storage centres, search engines, smart decisions and data mining approaches.
- Application layer: Provides an interface for user interaction (Fang et al. 2013; Gubbi et al. 2013).

While the Internet of Things enabled technologies cover a variety of fields and areas, this thesis focuses on the combination of the Internet of Things with Serious Games.

Internet of Things applications vary in disciplines from government agencies and the private sector to academic research projects. The Internet of Things is applied in transportation (for monitoring wear of parts through sensors and providing traffic and route information to passengers amongst others), logistics (enabling wireless payments, with recent advances made by Apple via the introduction of Apple Pay), environmental monitoring (noise pollution, air pollution, and climate change), healthcare (rehabilitation and data collection) and others (Atzori et al. 2010).

Radio-frequency identification (RFID) technology (Welbourne et al. 2009; Yang 2014; Po et al. 2013) was firstly proposed to label smart objects for tracking location (Yang & Wu 2014; Welbourne et al. 2009), movements (Yang 2015), or provide an ecosystem experience (Welbourne et al. 2009). Research has expanded the Internet of Things with more technologies including sensors, network, data analysis, and various applications. Its applications include diverse and wide fields such as; industries (Jia et al. 2012), environments (Sun 2012), cities (C.P. 2014; Zanella et al. 2014), transportation (Guerrero Ibanez et al. 2015) and healthcare (Deng et al. 2015; Yang et al. 2015; Spanakis et al. 2014).

2.3.1 Student Engagement and the Internet of Things

The Internet of Things paradigm monitors progress from the physical world and represents it in the virtual game environment. Additionally, the Internet of Things allows for the investigation of correlations between student behaviour and events in the physical world. The Internet of Things allows interconnected devices and sensor networks to gather such participant data. With modern society adopting technology in their daily lives, games accomplished through the Internet of Things allow for positive behavioural measurement, without excessive intrusion.

The vast amount of stored data sourced from interconnected devices generates a need for new methods of data analysis to produce meaningful results. Computer algorithms can be utilised to translate a variety of data types into conclusive results. Computers algorithms provide systematic instructions to a computer in order to complete a given task, which in turn are transformed into mathematical equations. Combining data sourced from interconnected devices with serious games would provide participants with informative play and allow researchers to better understand users' in-game choices and monitor user progression for completing a given game objective.

The core difference between the aforementioned research and this project lies in the methods of data collection and data analysis. The Student Engagement Instrument (Appleton et al. 2006), and others obtain data through questionnaires, either during classroom time or at random intervals. This project embeds attendance as a measure, achieved through a hybrid sensor network (Melthis et al. 2016), and utilises the Internet of Things to inform.

The combination of a sensor network with real-world data will allow correlations to be drawn. These data associations allow for personalised prompting based on behaviour pattern. In detail, if a student tends to be absent on a rainy day, a personalised prompt can be created for the next time it rains to highlight that fact to the student.

The surveyed research tends to focus on RFID technology to achieve location tracking (Wu et al. 2013; Yang 2014; Ashton 2009). This project will utilise Bluetooth to create a more pervasive experience for students that works around their timetable. The following section focuses on topologies that exist in the Internet of Things that are useful for integrating with Serious Games.

2.4 Internet of Things and Online Games Topologies

Existing topologies from networked games and the Internet of Things can be utilised or adapted to accommodate for Smart Serious Games, therefore it is not necessary to define topologies this purpose.

Table 2.1 presents the topologies discovered from this literature survey (Aldrich 2009; Favorskaya et al. 2015; Lotfi & Mohammed 2014; Armitage et al. 2006; Ashton 2009; Yang & Wu 2014). The table focuses on three key elements of topologies, considered for Smart Serious Games, scalability, Quality of Service (QoS), and security. The table illustrates that no topology covers all elements; however, there are advantages to the existing topologies.

Section 3.2 details the proposed topologies for integrating Serious Games and the Internet of Things. Below, this thesis provides a critical analysis of the topologies stated in Table 2.1.

TABLE I
TOPOLOGY COMPARISON

	SURVEYED TOPOLOGIES	Topology (7)	(8)	(9)	(10)	(11)	(12)	(13)
Scalability	sensor compatibility				✓	✓	✓	✓
	web datasets				✓	✓		
	energy efficiency					✓	✓	✓
	node flexibility				✓	✓	✓	✓
	peak demand	✓	✓		✓			
	peer bandwidth	✓	✓	✓				
	mobility				✓	✓		✓
QoS	low power consumption				✓	✓	✓	✓
	resource optimisation	✓		✓	✓	✓	✓	✓
	parameter based QoS	✓	✓	✓	✓			
	priority based QoS	✓	✓	✓	✓			
Security	low power protocols					✓		
	encryption	✓				✓		
	physical placement	✓	✓	✓				

Table 2.1 Topology comparison of surveyed research

2.4.1 Client-Server Topologies

The online gaming client-server architecture included in the literature by Armitage G et al. (2006) provides an example of existing topologies for networked games that can be adapted for integrating Serious Games and the Internet of Things.

In client-server architectures, clients require a service from the server. Clients cannot intercommunicate directly, but rather send messages through the server (Armitage et al. 2006). A large limitation of the client-server architecture is its focus on the server. If the server became unresponsive and disconnected, the whole network would become redundant until the server is reinstated in the network.

A peer-to-peer topology can also be adapted for combing Serious Games and the Internet of Things. A peer-to-peer topology for Massively Multiplayer Online Games suggested by Yahyavi and Kemme, offers greater scalability over client-server architectures, due to a better-distributed network load (Yahyavi & Kemme 2013). The Internet of Things is expanding rapidly, with continuous developments in low energy sensor devices and data analytics. To accommodate all the hardware included in the future of the Internet of Things ecosystem, scalability should be considered as a key element. These favours the use of elements from a peer-to-peer topology that harness scalability.

The MOPAR project developed a hybrid architecture for online games that focus on interest management, utilising peer-to-peer mobile technologies (Yu & Vuong 2005). The aforementioned project did not produce a topology but resulted in a hybrid solution with key advantages in scalability and fault tolerance over previous approaches, values that prove beneficial for integrating the Internet of Things and Serious Games, with a focus on mobile technologies.

2.4.2 Cloud Topologies

The research of Mishra et al. (2014) into the utilisation of cloud architecture for online games, suggested a two-tier cloud architecture where Tier 1 is formed by public cloud services and Tier 2 consists of the servers that are closest to any given gamer. The paper of Mishra et al. (2014) did identify limitations in their proposition related to pricing and potential security risks stemming from the cloud. A full cloud integration may prove beneficial for integrating the Internet of Things with Serious Games due to the scalability and decentralised nature of such a topology. Current cost restrictions favour a hybrid architecture, particularly for research purposes.

Cloud-centric Internet of Things presents the idea of cloud computing forming the core of the Internet of Things with users, sensor networks, middleware and private clouds completing the paradigm (Gubbi et al. 2013). The framework Gubbi et al developed creates a scalable Internet of Things for multiple applications. When considering the Internet of Things from a scaled-back perspective, such a representation becomes accurate. For the combination of Serious Games and the Internet of Things, consideration must be given to smaller infrastructure also, as not all event driven games that require the Internet of Things may require the cloud. For instance, a serious game may operate with a localised server, using sensors and actuators placed in a single room and open source data, which fundamentally affects gameplay.

2.4.3 Wireless Sensor Network Topologies

When utilising Wireless Sensor Networks in an Internet of Things solution, the level of integration required must be determined. Alcaraz et al. (2010) have outlined two approaches for integrating the Internet of Things and Wireless Sensor Networks: Stack-Based and Topology-Based.

Focusing on topology-based approaches two solutions were outlined: Hybrid and Access Point. Hybrid solutions feature networked nodes that can connect to the Internet autonomously, providing the network with redundancy and intelligence. Access Point solutions rely on a sink node for connectivity to the Internet, meaning nodes at the edge of the network have fewer capabilities and specify the data attempted to be captured, for example, movement. The research of Alcaraz et al. (2010) confirms that the potential of Wireless Sensor Networks is unleashed when integrated into the Internet of Things.

Developing a large scale Wireless Sensor Network is currently challenging due to the variety in domains, vendors and standard (Khalid et al. 2014). From the Serious Game context, an interconnected Wireless Sensor Network creates new possibilities for gamifying new scenarios and creating pervasive games that interact with the physical and virtual environment. An effective Wireless Sensor Network topology should be scalable, energy efficient and reliable (Atzori et al. 2010). D. Zhang et al. (2012) introduced a new approach for a weighted Wireless Sensor Network topology which identified sink holes amongst sensors and defined a new edge weight. Their research aided in the prevention of energy holes for Internet of Things networks. The scale of a network for the integration of Serious Games and the Internet of Things would form the likelihood of energy holes. Larger networks for Serious Games that combine the Internet of Things, that gather a greater amount of real-world data should utilise a weighted-Internet of Things topology.

Serious Games and the Internet of Things must consider Human-centric Wireless Sensor Networks (HWSN), due to the focus games place on players. Unlike Wireless Sensor Networks, Human Wireless Sensor Networks require that every networked node sends information to a Human Based Sensor (HBS) (Ochoa & Santos 2013). This type of topology would be ideal for games or Serious Games that monitor specific body parts or require body scanning, such as brain activity. Human Wireless Sensor Network topologies can benefit games that require players' current location. Similarly, Body Area Networks (BAN) are utilised for medical, lifestyle and entertainment purposes. BANs comprise of sensors and actuators, placed in, on and around the body (Patel & Wang 2010). For the proposed application, a localised hybrid, Wireless Sensor Network topology will be utilised, detailed in Section 5.2.

2.5 Data Analytics and Game Analytics

The following research forms a foundation for the data algorithms this thesis defines for measuring student engagement through a Smart Serious Game.

Data analytics describes the computational analysis of structured and unstructured data. Data analytics proves effective for a variety of applications, from healthcare (Raghupathi & Raghupathi 2014), Big Data (Gandomi & Haider 2015; Lavalle et al. 2011), and games (Loh & Sheng 2013; Loh et al. 2015; Drachen et al. 2013; Hauge et al. 2014; Medler 2009)

Raghupathi and Raghupathi (2014) surveyed literature on healthcare and data analytics, with a focus on Big Data and its effects on the industry. Big Data has been defined as primarily unstructured data of large quantity, velocity and variety (Gandomi & Haider 2015). Raghupathi and Raghupathi concluded that analytics and Big Data provide better-informed decisions and insights into accumulated data. The proposed application of this thesis does not meet the definition of Big Data due to the volume and velocity of the data, however, the proposed framework for integrating Serious Games and the Internet of Things would still stand viable for applications that utilise Big Data.

A survey into data analytics for Big Data by Gandomi and Haider (2015) emphasised the lack of data analytics methods for unstructured data sets, which account for 95% of data relative to Big Data. Their survey accounted for a variety of data analytic sources such as audio, text and video. The proposed framework for this thesis does not confine itself to structured or unstructured data. The flow of data and the merge of the technologies define the interconnection required to develop a Serious Game that integrates with the Internet of Things. The application of the proposed framework, however, will utilise structured data, obtained from Web API and an intrinsic wireless sensor network.

Research by Lavelle et al. (2011), focused on Big Data and data analytics for industrial organisations, and discovered a correlation between top performing organisations and the use of data analytics. Furthermore, their research predicted data visualisation to prove valuable for organisations that seek to understand consumer bases and increase profit margins. Their research highlights the power of data analytics and the important role they play in the industry sector. This thesis presents a framework for integrating Serious Games and the Internet of Things that can be utilised outside the scope of academia.

Game analytics describes the process of data analysis for game development and game research (Drachen et al. 2013). In detail, game analytics allow researchers to access the effectiveness of a game against its targets set at the development stage. Game analytics will allow this project to assess the proposed application of our framework.

Drachen et al. (2013) specify telemetric data can be stored in databases, for the use of average measurements with meaningful results. For the proposed application of this thesis, telemetry data obtained from an intrinsic wireless sensor network will be stored in a hosted database, for the measurement and representation of student engagement. The data for the proposed application meet the classification of user and performance metrics (Drachen et al. 2013) as it relates to user performance, and the same metric affects gameplay and game progression.

Medler (2009) categorised game history data into four forms; concurrent, progressive, longitudinal, and external. The data derived from Serious Games that integrate the Internet of Things fall into all categories. Concurrent data relate to data obtained from intrinsic and/or extrinsic sensor networks, data from gameplay form progressive data, longitudinal data contextually apply to the lack of gameplay and sensor activity, whereas external data is can refer to the environmental data obtained from web API. The proposed application primarily focuses on concurrent, progressive, and external data, to represent student engagement in-game and correlate behaviour to events occurring in the physical environment.

Research by Hauge et al. (2014) investigated the implications of using learning analytics with Serious Games. Their research proposed a framework for in-game analytics and described the use of in-game and post-game analytics. Although their research focuses on learning analytics, Serious Games that integrate the Internet of Things, encompassing data analytics, will feature in-game and/or post-game analytics, as the data obtained from the Internet of Things directly affect gameplay. The application of this thesis will utilise post-game and in-game analytics to affect gameplay. This is due to the nature of event-driven Serious Games, where on a specific date and time, the game will perform calculations.

Loh and Sheng (2013) researched into performance metrics for Serious Games and proposed using string similarity metrics. They applied string similarity metrics to differentiate between novice and expert players of a defined game level. The results highlighted the effectiveness of utilising metrics other than high scores to obtain meaningful results in Serious Games. Loh et al. (2015) furthered research into game analytics for Serious Games by surveying the existing methodologies of performance measurement in the domain. Their research found there was a need for transforming data analytics into actionable insights. The integration of the Internet of Things with Serious Games promotes such transformation. The proposed application of this thesis portrays insights gathered from intrinsic and extrinsic sensor networks, into human behaviour in-game, allowing participants to act on the information, and generating the potential to improve in-game performance.

This literature survey did not discover any research on measuring student engagement through data analytics and Serious Games. This section stated the benefits of data analytics and game analytics uncovered by previous research, focusing on the improved performance measurements game analytics provides. Therefore, this section justifies applying a Smart Serious Games solution into proposing an improved metric for student engagement.

This thesis utilises the Internet of Things to obtain data from intrinsic and extrinsic sensor networks, which affects the gameplay of a Serious Game. The following section presents existing research and applications that combine the Internet of Things with Serious Games, whilst highlighting the necessity of this thesis in the upcoming academic field.

2.6 Smart Serious Games

The term Smart Serious Games defines Serious Games that have integrated with the Internet of Things ecosystem (Favorskaya et al. 2015). By nature, these games are data-driven, or event-driven. The use of the Internet of Things gaming technologies complements advances in augmented reality and virtual reality gaming. This section presents the latest research in the domain and details why this research applies to it.

As the research area of Smart Serious Games is young, literature is limited, with some research projects beginning to include the term as future works (Lotfi & Mohammed 2014; Elaachak et al. 2015). It is very important to continue research into Smart Serious Games as the Internet of Things delivers interconnected sensors for better data acquisition and a pervasive experience, elements that create quantitative results with less intrusive methods for obtaining them. In addition, player behaviour can be analysed in correlation to new sets of data, something previously not possible.

In a truly interconnected Internet of Things ecosystem, Serious Games could harvest and analyse data from players' physical worlds and present it to provide better player behaviour insights. Improving player insights allows game developers to improve gameplay, provides stronger conclusions on research surrounding games and Serious Games, and allows the industry to tailor in-game content to match player satisfaction, amongst other things. The combination of Serious Games and the Internet of Things has recently been termed as Smart Serious Games (SSGs) (Favorskaya et al. 2015). SSGs have been defined as the merger of smart technologies, including devices and services, and the principles of Serious Games (Favorskaya et al. 2015). Their literature details the combination of the advantages of both technologies and its future utilisations including analytics for cooperation, a tool for solving serious problems and others. This thesis does integrate the Internet of Things with Serious Games and investigates the benefits of data analytics on student engagement measurement, by defining a modular framework for the development of relevant solutions.

2.6.1 The Effect of the Internet of Things

By combing the Internet of Things into Games or Serious Games, a seamless exchange of information between virtual services, real items and products is established (Fleisch 2010). Researchers are investigating this theory, by using a variety of wearable devices or sensors to implement an augmented/virtual reality of gaming experience.

Recent advances in the Internet of Things offer the potential for service specific applications of Serious Games. For instance, the utilisation of Barcode technology into an online game. R. Adelmann et al. (2006) developed a social network game (Product Empire) which motivates users to scan barcodes and to enter basic product information. The experiment results show that this attempt at integrating Internet of Things into Serious Game generates a potentially open product repository, improving customer-shopping experiences.

The Internet of Things can help serious games become more pervasive, and extend gaming from the virtual to the physical world. Computer games played through converging physical and virtual worlds using receptive technology can be defined as pervasive games (Laine & Sedano 2015). By making Serious Games more pervasive, players are less involved with input technology and more focused on gameplay, improving player immersion (Lv et al. 2015). This means that a pervasive, gamified real-world task can positively measure player behaviour.

2.6.2 Smart Serious Games Applications

Research into developing Smart Serious Game solutions is of a preliminary nature and falls short of an extensive outlook on the domain (Pokric et al. 2015; Garcia-Garcia et al. 2017; Konstantinidis 2017). In detail, Pokric et al. (2015) investigated the use of augmented reality Internet of Things services encompassing Serious Games. Their research focused on the environmental benefits of such a system, though their research did not utilise the term Smart Serious Game. The research by Pokric et al highlights the integration of physical and virtual worlds for the benefit of a player through a set goal. This principle stands true in Smart Serious Games and is utilised in the proposed application of this thesis.

Research by Garcia-Garcia et al. (2017) introduced the early stages of their project into improving energy efficiency in a building by combining Internet of Things data management and Serious Games. Their research fails to state Smart Serious Games as the application domain.

Konstantinidis (2017), described the integration of Serious Games and the Internet of Things as an interplay and did not reference the term of Smart Serious Games. Furthermore, his research focuses on the use of Smart Serious Game solutions for personalised healthcare through local motion capture devices, activity and health trackers, and intrinsic sensor networks. His work provides an indication to the future of Smart Serious Games, citing the benefits in engagement through such solutions.

Further research is required to determine the true potential of Smart Serious Games into the domain and into various applications. This thesis adds a stepping-stone to this academic field and encourages further research into relative avenues.

2.6.3 Serious Games Frameworks

There is a vast amount of literature surrounding serious game methodologies, and frameworks, including surveys of such publications. Currently, there is a limited number of modular frameworks for the combination of Serious Games and the Internet of Things. Literature is continuously emerging, however, most works are of a preliminary nature, or are service specific (Kim 2017), or offer insights towards a framework for Smart Serious Games (Hassan et al. 2012). This section provides the identified research pieces that illustrate some form of a modular framework for serious games.

S. Tang and M. Hanneghan (2013) identified a model-driven framework for Serious Games. Their paper encourages the development of serious games for educational purposes by multidiscipline domains. Their framework is modular and therefore encourages adaptation for service-specific applications. The proposed framework utilises their modular approach to allow future works to adapt it to meets a project's needs.

S. Arnab et.al. (2015), introduced a framework for Serious Games focused on pedagogical use. Their framework centre's on coherently merging the attributes of pedagogy and games in order to produce better educational games. S. Arnab et.al, outline a detailed and effective framework for use in such games, elements of which apply to event-driven games in an educational setting, such as this project. However, this thesis furthers any form of Serious Games framework by integrating the Internet of Things and outlining the modular interconnection between the technologies.

Kiili et al. (2014) presented a framework for achieving flow in educational games. Their publication focuses on linking educational theory with game design and presents a valid contribution to maintaining engagement in educational games. Their research is of a service-specific nature and provides additional points for consideration when defining a framework for Smart Serious Games, particularly for Smart Serious Games solutions relative to education.

Cowley et al. (2011) published a novel approach to serious game design by introducing smaller game elements into a framework instead of constructing a service-specific one. This approach leads to the creation of a modular framework where game development can start at any stage based on the principle developed. This modular approach coexists in our solution; however, we focus on producing a modular framework for the integration of the Internet of Things and Serious Games that can be utilised to accelerate the production of such applications and further the surrounding academic field.

Research into serious games for obesity by Hassan et al. (2012) produced a framework capable of obtaining real-time sensor information from Body Sensor Networks (BSNs) that feed into a game and suggest improvements directly to the players regarding exercise and nutrition. This real-time approach is relative to some elements, or modules of this thesis' proposed framework. Hassan et al, successfully outline the technologies required for a game labelled as pervasive, but relative to the Internet of Things. We extend this type of research by defining an application-neutral topology with a modular outline that will aid researchers to develop service-specific Serious Games for Games that embed the Internet of Things.

2.6.4 Smart Serious Games Frameworks

Due to the physical and networking nature of the Internet of Things, topologies can be more useful than frameworks for Internet of Things based applications. We have proposed a topology for the application area of this research, detailed in the following chapter, and have reviewed current game and Internet of Things topologies to suggest those best for the development of Smart Serious Games. A plethora of research exists on service-specific topologies for the Internet of Things. The following chapter identifies those that relate closest to Serious Games.

There is a distinct lack of frameworks for the integration of Serious Games and the Internet of Things. Some research is beginning to prevail such as Kim (2017), which discusses the integration of Internet of Things and games with games as a service. Through his research, several circuit diagrams arise as well as a blueprint for the interconnection of mobile clients and server. As his research is, service specific and of a preliminary nature, the paper falls short of producing a reusable, modular framework.

Producing a modular framework for the integration of Serious Games and the Internet of Things requires a neutral perspective, in which fellow researchers may swap or adjust the framework to suit their research's needs. To achieve this, the proposed framework clearly identifies the technological boundaries of Serious Games and the Internet of Things and demonstrates the interconnecting technologies in a top-down hierarchy.

2.7 Research Directions

This chapter presented the relevant research surrounding the development of a modular framework for Serious Games and the Internet of Things along with the required research for the case study that aims to validate the proposed framework. Based on this survey this thesis sets out to bridge the gap in literature where no framework is modular and portrays the theoretical relationship of the technologies, irrespective of a set application.

Following the development of such a framework, this thesis utilises the measurement of student engagement through a Smart Serious Game. This thesis does not set out to produce a new measure of engagement that replaces current measures, nor does it focus on this deliverable as its aim, however, this thesis will produce a computer algorithm that encompasses self-reflection tools with data from the Internet of Things.

Future research directions derived from this thesis are difficult to scope due to the versatile nature of the proposed modular framework. Therefore, it is adequate to state that this thesis will impact future research of any application that combines games with the Internet of Things.

2.8 Chapter Summary

This chapter encompasses the literature survey undertaken to define the scope of Smart Serious Games and the latest research in the domain. The chapter begins by detailing notable and relative research into Serious Games and Gamification. Continuing, the chapter discusses the Internet of Things ecosystem along with the benefits it produces when integrated into services.

Internet of Things and online game topologies are surveyed, to highlight the networking interconnection that is required for Smart Serious Games, and to draw on the common elements of the aforementioned topologies, thus resolving any necessity of defining a bespoke topology. Additionally, this chapter presents research into data analytics, and game analytics, displaying the benefits for their inclusion in Serious Games and Smart Serious Games. Finally, this chapter presents the existing definition of Smart Serious Games alongside the latest research in the domain and relevant frameworks, used to develop the proposed framework in this thesis. The following chapter will survey the network topologies for Smart Serious Games by accounting for the network requirements presented by such applications.

CHAPTER 3 – TOPOLOGIES FOR SMART SERIOUS GAMES

3.1 Introduction

The following chapter presents the appropriate topologies for combining the Internet of Things with Serious Games, based on the undertaken literature survey. Additionally, this chapter outlines the requirements that topologies need to meet when considered for a solution that combines the Internet of Things and Serious Games and details the topology this project utilises for the developed application. No new topologies are presented in this chapter. The topologies form a review of existing online gaming topologies reimagined for the inclusion of interconnected devices.

3.2 Internet of Things Topologies for Serious Games

The reviewed topologies and requirements in Section 2.4 highlights the incompatibility of traditional topologies with the requirements of Internet of Things topologies for Serious Games. The following section presents updated variations of notable topologies for Smart Serious Games.

3.2.1 Client-Server and Peer-to-Peer

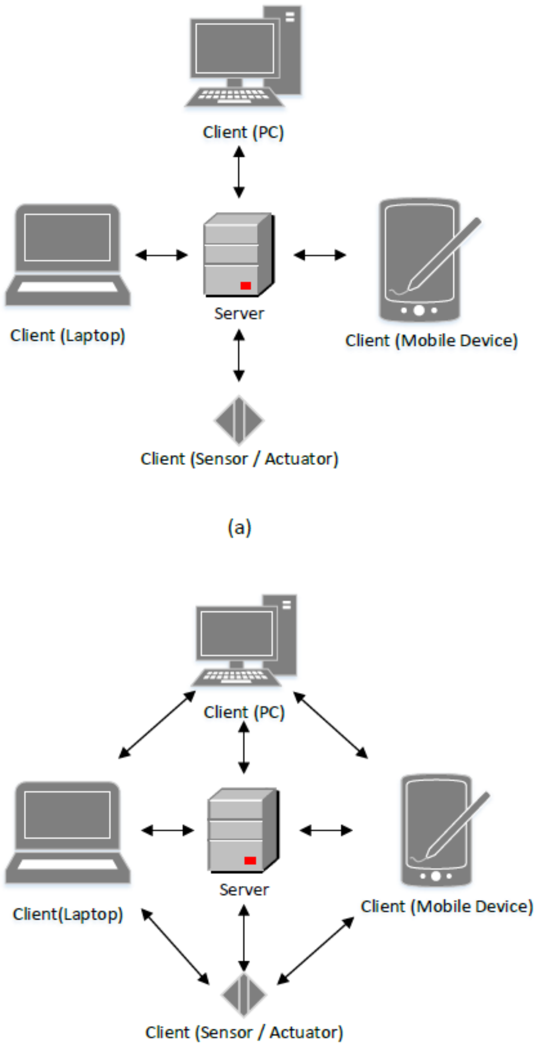

Figure 3.1 (a) Client-server topology, (b) Peer-to-Peer client-server hybrid

Section 2.4.1 presented client-server and peer-to-peer topologies for online games. Figure 3.1 proposes a client-server architecture and a peer-to-peer client-server hybrid topology that is adapted for the Internet of Things ecosystem. The proposed architecture will share elements of a peer-to-peer architecture but will fundamentally differ in the roles clients have within the network. A combination of sensors and computational devices form the clients in this topology. An additional difference is the intercommunication between clients. Clients will need to communicate with each other directly.

3.2.2 Interconnected Access Point

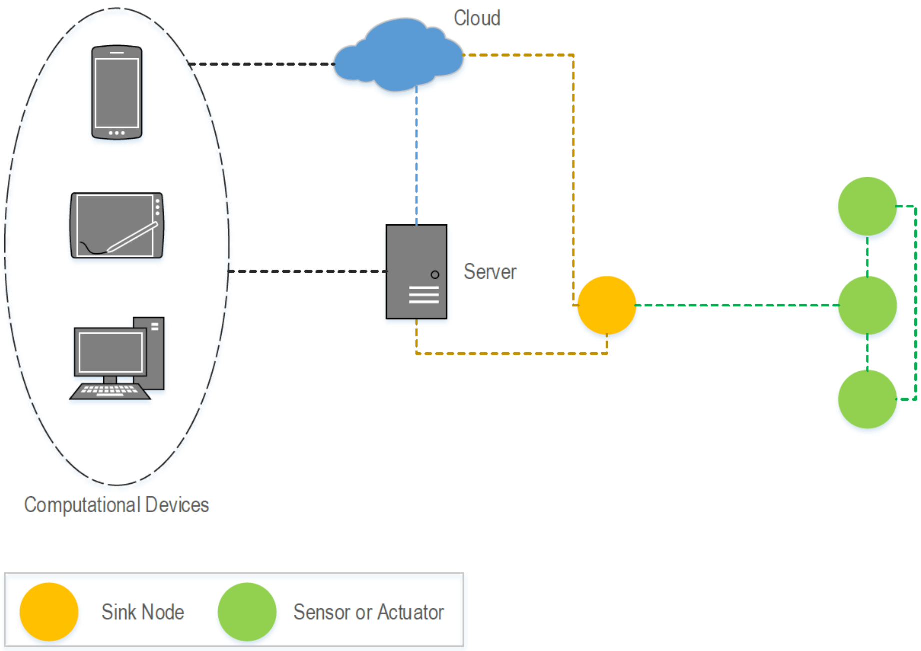

Figure 3.2 Interconnected - Access Point Topology

The interconnected access point topology, illustrated in Figure 3.2, is better utilised for solutions that involve multiple users and locations such as an augmented reality, Massive Multiplayer Online (MMO) game. This is due to the small clusters of sensors and actuators formed with the sink node, allowing several low powered nodes to be placed in a variety of locations. Father.io[3] examples an augmented reality MMO game that could utilise an interconnected access point topology. Focused on merging smart devices with Personal Computer (PC) gaming, Father.io utilises smartphones to augment players' physical perspective and enable them to engage in an MMO shooter. The video trailer displays a smartwatch, utilised in-game alongside a smartphone. To achieve this data must flow between smart devices to allow for a fluid gaming experience. Data could be synced via a sink node, or the smartphone could be utilised as such, however, devices could also be

[3] https://www.indiegogo.com/projects/father-io-massive-multiplayer-laser-tag-app#/ Accessed 20/11/17

connected autonomously, as illustrated in the hybrid topology. Father.io is currently a concept but presents an insight into the future of Internet of Things games.

In all suggested topologies, sensors describe devices that detect player activity (for example location and movement) and transmit it either autonomously or through a sink node. Actuators detail interconnected devices that provide player feedback as a means of transcribing a game event such as level completion and confirmation of the game event. Nodes comprise of actuators or sensors in all suggested topologies.

3.2.3 Decentralised Peer-to-Peer

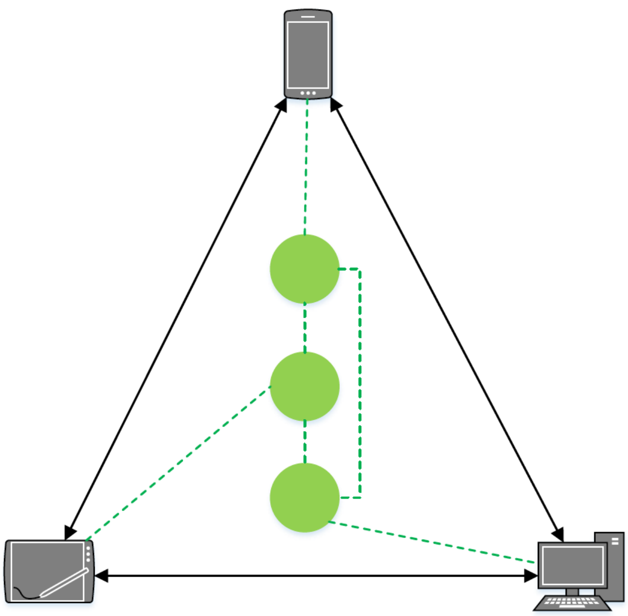

Figure 3.3 Decentralised Peer-to-Peer topology

Utilising a peer-to-peer topology for combining the Internet of Things and Serious Games should consider the size and demand of the network required. Dependant on the game requirements, a Smart Serious Game could utilise this topology with no central server, but rather through computational devices that store and distribute game sections and interact with interconnected sensors and actuators based on a player's location, as illustrated in Figure 3.3. Such a topology could be utilised for Smart Serious Games that are not resource demanding.

Although the processing power of smart devices is constantly increasing, they are still unable to store and process large virtual world data. Revisiting Father.io as an example, this game would suffer in a peer-to-peer topology due to the vast amount of location data that would need to be stored on smartphones and smartwatches. It could be argued that in the not so distant future, mobile smart devices may well be capable of doing so, however soon peer-to-peer topologies in SSGs should consider games with limited virtual environment.

3.2.4 Hybrid

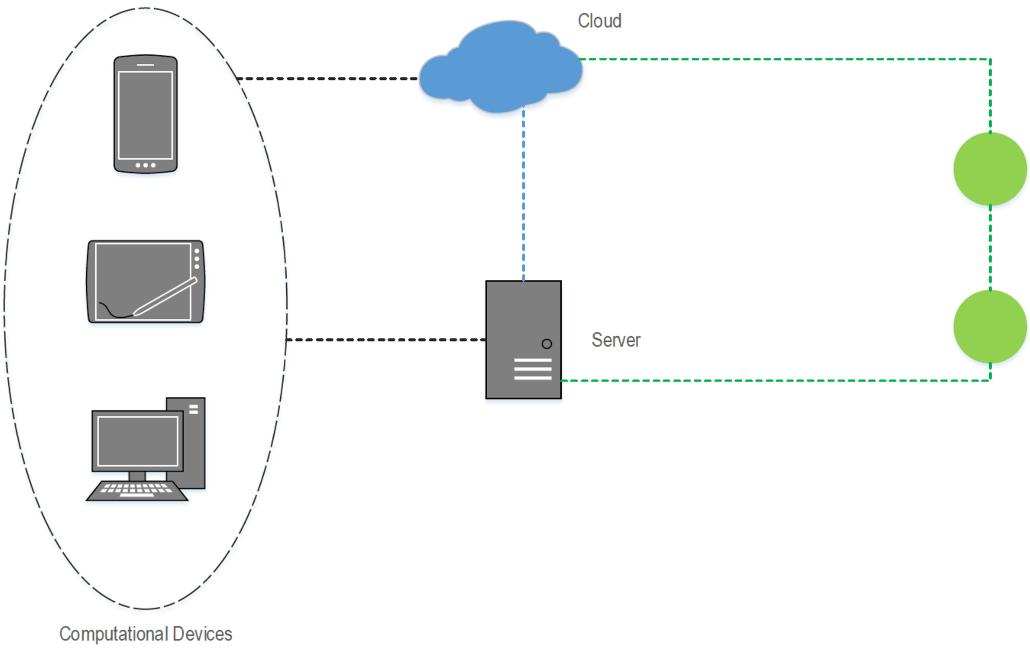

Figure 3.4 Hybrid topology

A hybrid Wireless Sensor Network topology shown in Figure 3.4 for Smart Serious Games would feature autonomous nodes, removing the sink node from the network architecture. By autonomous, this thesis describes nodes with Internet connectivity. In this case, the location of the nodes is dependent on the game requirements. Numerous locations can be used, provided that all positions provide access to Internet and power. Power management is a key element in hybrid topologies, as the inclusion of connectivity requires more power for each node attached to the network. Hybrid topologies can be utilised for a variety of Smart Serious

Games due to their versatility with deployment. As previously mentioned, Father.io could utilise a hybrid topology to provide all smart devices with autonomous connectivity. This improves the network robustness as it removes the dependency of a sink node.

A key difference between the use of topologies for Smart Serious Games and other uses such as Wireless Sensor Networks can be noted in the data that flows through the network. When considering a Smart Serious Game topology, the data sourced from sensors and sent to actuators can be described as events. This is because any data that derives from a sensor or web datasets would inflict a change or an event in gameplay. For example, a Serious Game that monitors student engagement with a programme would input a location check-in and translate it into a gameplay events such as user score, level up and increased inventory.

3.3 Requirements for Smart Serious Games Topologies

Armitage et al. (2006) state that a topology for games must consider data packet loss, latency and jitter to create a fluid gaming experience. The requirements for Smart Serious Games topologies have not yet been defined in the current literature. We propose the following key requirements based on the conducted research:

- Scalability
- Quality of Service (QoS)
- Security

3.3.1 Scalability

Scalability is an ambiguous concept, as it is service specific. For a Smart Serious Game topology, scalability must consider Wireless Sensor Network and gaming network attributes. To incorporate the Internet of Things into a game, data must be sourced through sensors, either intrinsically or extrinsically. By extrinsic sourcing of data, we consider datasets available on the Internet through APIs. To account for the network demands of a sensor-based solution, Wireless Sensor Network topology requirements are essential. A scalable Wireless Sensor Network topology allows nodes to be added without major reconstruction or development (Atzori et al. 2010) by accounting for the node density of a given topology (Akyildiz et al. 2002). Furthermore, consideration is given to the energy efficiency of a Wireless Sensor Network topology. To achieve efficiency, the least amount of power should be utilised for the network to operate reliably, and sleep modes should be operational where possible for nodes that are not constantly active (Atzori et al. 2010). Aside from the sensory requirements of a Smart Serious Game topology, the gaming network demands must be met. From a gaming perspective, a scalable network must adapt to peak demand and peer bandwidth (Schiele et al. 2007). Depending on the size of a player community, demand can soar during off-school hours and significantly affect gameplay. Peer bandwidth will affect data demanding games that require large files to be sent back and forth from a server. Contrary to a traditional peer-to-peer network, a Smart Serious Game topology must consider mobility in nodes (Zorzi et al. 2010) as household devices adopt more Internet-connected equipment with embedded sensors, such as microphones.

3.3.2 Quality of Service (QoS)

Smart Serious Games topologies must adhere to Quality of Service (QoS). The required components to achieve Quality of Service for Smart Serious Games can be sourced by considering Wireless Sensor Networks and networks for online games. From a Wireless Sensor Network perspective, Quality of Service can be achieved by considering the low power consumption attribute of sensor networks (Akyildiz et al. 2002). Research by D. Christin et al. (2009), recommends heterogeneous sensors contribute to assure Quality of Service by optimising network resources. When considering the gaming element of a Smart Serious Game topology, a lack of Quality of Service can detrimentally reduce the effectiveness of an application, for example, latency on real-time, real-world data required to affect gameplay. Networks for online games implement parameter-based and priority-based Quality of Service (Armitage et al. 2006), to ensure a reduction in latency and provide a fluid gaming experience. A balance of low power consumption and network latency for accommodating future Smart Serious Games applications that support multiplayer and data from sensors and mobile devices can be generated by incorporating the elements of Wireless Sensor Networks and online game networks for Quality of Service.

3.3.3 Security

The security of a topology can be divided into two categories; *physical* and *network*. The physical placement of sensors and actuators must consider vandalism and burglary, particularly when expensive hardware is involved. Security of smart devices must also be considered as they become embedded into Smart Serious Games solutions. Major manufacturers offer services such as remote wiping to prevent unauthorised access, however, Smart Serious Games should offer players the ability to remove their own devices from a network to maximise security. Allowing users to manipulate their own smart devices on a network can also improve scalability. From a networking perspective, sensors and actuators with Internet connectivity must utilise protocols and encryption mechanisms that prevent malicious attacks and theft of personal data. Due to the low power nature of sensors and actuators, research has underlined the necessity of new security mechanisms that can operate at low power (Christin et al. 2009). Further security requirements will be service specific.

3.4 Chapter Summary

This chapter presents the topologies that can be utilised for Smart Serious Games and the proposed topology for this project’s applications. After researching through the relevant scientific fields and paradigms, presented in Section 2.4, three topologies were suggested;

hybrid, interconnected access point and peer-to-peer. These topologies would cater for most games that utilise sensory input, distributed over a network.

This chapter also presents the notable requirements for defining a topology for Smart Serious Games, extracted from the literature survey presented in Section 2.4. For service specific topologies, the list of requirements may differ and by a greater length. The following chapter presents the proposed framework for Serious Games and the Internet of Things and discusses the requirements for the development of such a framework.

CHAPTER 4 – A PROPOSED FRAMEWORK FOR SMART SERIOUS GAMES

4.1 Introduction

Developing Smart Serious Games presents significant technical challenges. The Internet of Things revolves around a bank of hardware and protocols that vary greatly. ‘Smart’ products for industrial and household applications, are increasing the number of devices related to the Internet of Things, and subsequently its potential. Serious Games, however, focus on software development and deployment. Linking the two technologies requires standardisation that aids future development.

This chapter presents a modular, interconnected framework for the development of Smart Serious Games. The literature on such a framework is limited to service specific solutions, with research focusing on discovering the potential of Smart Serious Games and defining its presence in the academic field (Favorskaya et al. 2015; Konstantinidis 2017; Garcia-Garcia et al. 2017). The proposed framework presents the modular interconnectivity of Smart Serious Games by accounting for Internet of Things sensor networks, middleware, and serious games. As the framework is modular, it is also adaptable, for use with other game types such as online games, gamification or edutainment. The proposed framework sets the foundation for further research of any application in the academic field. Additionally, this chapter states the requirements for defining a framework in the academic domain, focusing on attributes inherited from the Internet of Things.

4.2 Proposed Framework

In designing the framework, the key requirements needed for producing a framework for Serious Games and Internet of Things were determined, based on the aforementioned research. By meeting the following requirements, frameworks can ensure they provide a basis for a vast variety of applications within their domain.

4.2.1 Scalability

This requirement echoes the requirement we set in Section 3.3.1 when defining topologies for Serious Games and the Internet of Things. In online games, whether they be serious or not, the number of players can increase drastically depending on popularity spikes. We often see commercial games struggle to accommodate for players at launch as they incorrectly allocate resources at the server end. A relatively recent example of such a scenario was the launch of Grand Theft Auto V which saw players struggle to connect online due to the volume of requests. By incorporating the Internet of Things, new challenges arise. New physical locations could be added at any point for games that are location based. This would equate to new nodes or new sensor clusters that need to be connected to the same framework. In addition, new extrinsic sensor networks could be added using Application Programming Interfaces (API). Therefore, the scalability of a framework is essential for Smart Serious Games.

4.2.2 Topology Neutrality

When combining the Internet of Things with Serious Games, topologies form a core element of the integration between the two. It is the topology that will define the networking requirements of the framework. A challenge of developing frameworks for Smart Serious Games is avoiding defining one, based on a single topology. Topologies form a relationship with the network and middleware modules of a framework, therefore restricting a framework to a single topology would limit the scope and risk of the framework becoming service specific.

4.2.3 Application Neutrality

Application neutrality describes a framework that is not service specific. Application neutral frameworks present greater impact. The aforementioned background research (Kim 2017), provides an example of a lack of scope coming with a proposed framework, as there are specifics embedded, that are tailored to a single application. The proposed framework, detailed in the following section, conforms to application neutrality by defining the framework without including specific means for technologies, but rather presenting the technologies themselves.

Based on the undertaken literature review this thesis proposes the modular framework seen in Figure 4.1. The framework considers the data flow to begin from the top and end at the bottom. This flow is not the only form of data flow that can be had. Data will flow from the application layer through to the middleware layer. From there data will flow back down, updating the game state. This will form a data flow loop which allows game progression based on user input. An example of such a loop would be purchasing an item in the game. The game triggers the data request, if this request meets the correct conditions (user balance) then the request will be granted, and the game will be updated to reflect the change in inventory. The proposed framework encompasses four layers, sensing, networking, middleware, and application.

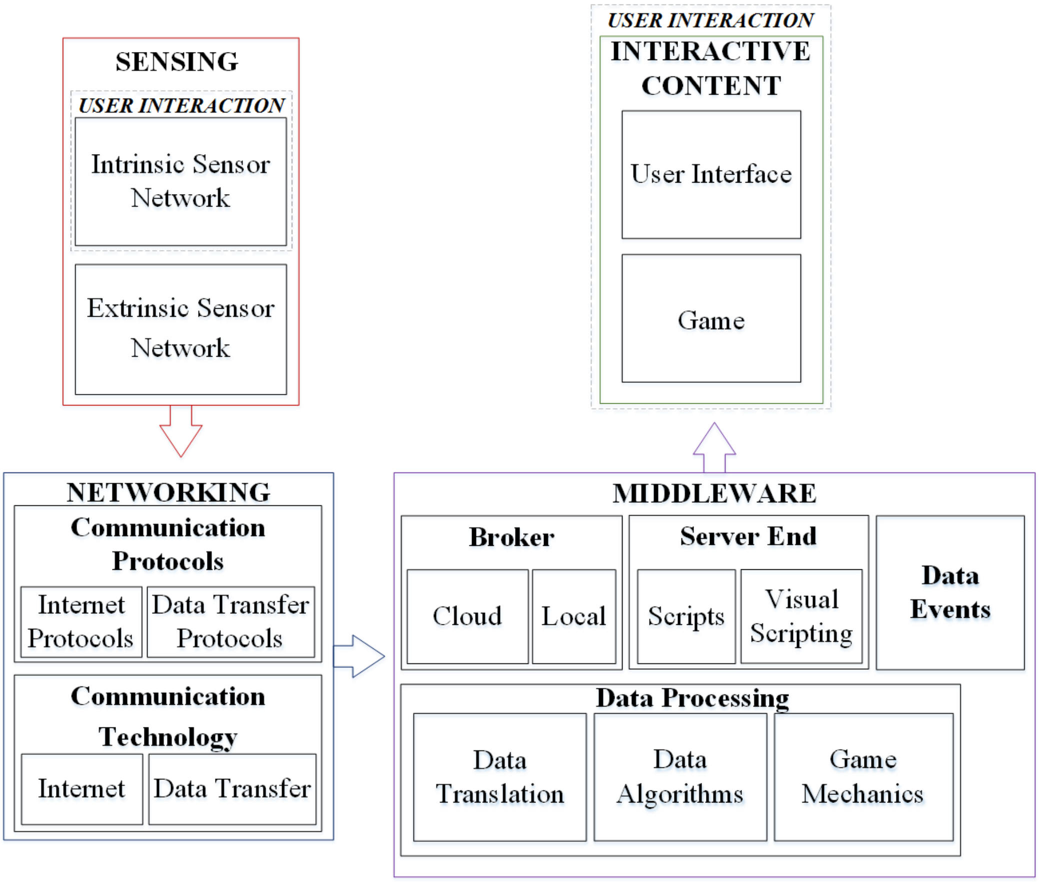

Figure 4.1 Modular framework for combining Serious Games with the Internet of Things

4.2.4 Sensing Layer

The Sensing layer defines all sensor networks that react with a Smart Serious Game, with or without direct human interaction. User Interaction with a Smart Serious Game does originate here, as data obtained from a sensor network will gather physical actions to be translated into game input. The sensing layer includes two modules, intrinsic and extrinsic sensor networks.

4.2.4.1 Intrinsic Sensor Network

Intrinsic sensor networks describe physical networks that have been developed or established for an application. Intrinsic sensor networks are responsible for sourcing the data required for game input and in turn game progression. These networks can be intrusive (human body sensor network, RFID) or non-intrusive (Bluetooth, Wi-Fi). It is the developer’s responsibility to choose an appropriate intrinsic sensor network based on the application requirements.

4.2.4.2 Extrinsic Sensor Network

Extrinsic sensor networks detail pre-existing networks that the users of an application may not come in direct contact with, whether intrusively or not. Such networks can be found in APIs such as traffic, weather and others, where largely based sensor networks feed in environmental data for various purposes. Furthermore, extrinsic sensor networks can exist in smaller physical spaces. For example, a building may contain RFID scan readers that transmit data through a sink node, for staff authentication and authorisation. In a Smart Serious Game, such data can translate to a game input, by recognising presence in a location at a specific time.

4.2.5 Networking Layer

The networking layer houses all the essential protocols and technologies that allow data communication of sensor networks to middleware. The networking layer explicitly considers the requirements for transmitting data between local or wide network, such as the Internet, and transmitting data between devices themselves, such as Bluetooth.

4.2.5.1 Communication Protocols

The data communication protocols module focuses on how data is structured and transmitted, in accordance with the communication technology used such as a wireless or wired network, including WWAN, WPAN, WLAN (Guinard et al. 2010). Developers of Smart Serious Games do not have to define a protocol, as the technology sets it, however, they must consider the protocol used by a communication technology, to ensure that the communication technology meets the game requirements.

4.2.5.2 Communication Technology

The communication technology module provides the networking aspects of a Smart Serious Game. These attributes vary from common online games, as the scope of technology widens with the inclusion of the Internet of Things. The intercommunication of devices, the sourcing of data from extrinsic sensor networks, and the balance between network latency and low power sensor networks provide new challenges that developers must consider and resolve when producing a Smart Serious Game.

4.2.6 Middleware Layer

The middleware layer forms the bridge between all layers, and for some data streams serves as an end, specifically data streams between interconnected devices. A vast amount of data transfer, data interpretation and translation, and data manipulation occurs here. The following sections detail all relevant elements.

4.2.6.1 Broker

The broker module accommodates for local or cloud-based brokers. The broker module is pivotal in the transmission and receipt of data between services, devices and servers that require a network, whether local or cloud-based. Every Smart Serious Game that requires an Internet connection to communicate with a sensor network will require a broker module.

4.2.6.2 Server End

The server end module accounts for all types of servers that can be associated with a Smart Serious Game. In detail, servers can be solely database storage, application servers or web servers. A focus for web or application servers is the scripts or visual scripting mechanisms that handle data from and to the broker. It is important to state the server end module outside the specifics for data manipulation, as it forms a pivotal element for Smart Serious Games.

4.2.6.3 Data Events

A Smart Serious Game will have some form of data events disregarding its application. Data events include triggering game notifications based on time, allocating points based on a player's physical location in each moment, within the intrinsic sensor network, and others. The events themselves can greatly vary based on the application; however, a game that does not require data events may not require the integration of the Internet of Things at all.

4.2.7 Data Processing Sublayer

The data processing sublayer is housed by the middleware layer and concerns a number of processing steps for handling raw sensory data (Xu et al. 2014), and other data derived from gameplay, including the construction of data storage centres, search engines, smart decisions and data mining approaches. Three modules are included in this sublayer; data translation, data algorithms and game mechanics. All three modules play a pivotal role for Smart Serious Games based applications. Figure 4.1 displays the interaction between the elements. Elements may interact with each other sequentially, at intervals or may not interact with each other at all. The interaction of the elements in this sublayer depends on the requirements of the Smart Serious Game. For example, if a Smart Serious Game requires data translation to directly instantiate game mechanics, data algorithms may be redundant, or be triggered at a specific data event. The following sections further explain this concept.

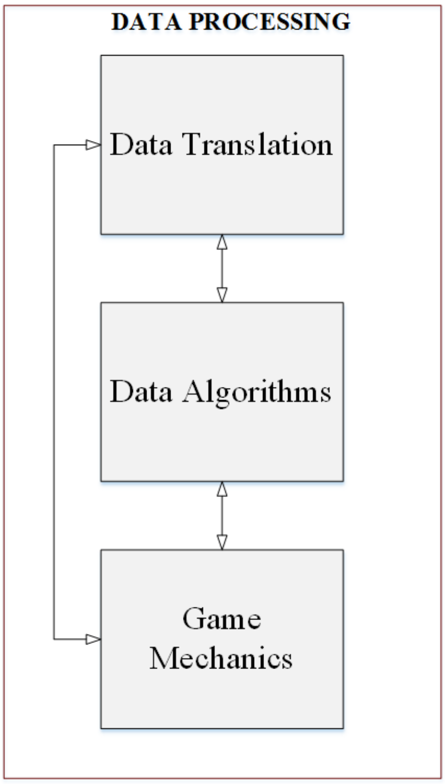

Figure 4.2 Element interaction in the data processing sublayer

4.2.7.1 Data Translation

The data translation element accounts for the process of converting data from a source to a type understandable by the receiver. For example, sensory data must be translated into a meaningful resource that can be utilised in the game. Data translation occurs in a game too, outside the scope of the Internet of Things. Conventional computer games translate input from a keyboard and mouse into an action in a virtual environment. The inclusion of the Internet of Things increases the data types and the amount of data translation required to perform a reaction in a virtual game environment from an action in a physical environment.

4.2.7.2 Data Algorithms

Data algorithms can then be used to summarise, or aggregate game points sourced from interconnected sensors, hence this layer specifies the data algorithm within this module too. It is the data algorithm module that could be removed for service specific applications, where sensory data forms a direct input in the virtual game environment. For example, an interconnected motion capture device with a heart rate monitor that is used only to represent these values in a game.

4.2.7.3 Game Mechanics

Any game type, whether included with the Internet of Things or not, includes game mechanics. It is the game mechanics that directly interact with data translation and trigger a reaction within a game, such as levelling a character up, unlocking an achievement and others. The Internet of Things adds complexity to the game mechanics by widening the scope for input devices and changing input from direct to indirect. By indirect, this thesis defines data sourced from interconnected sensors but stored, and only included in a virtual game environment through a data event.

4.2.8 Interactive Content

The interactive content layer provides an interface for user interaction (Fang et al. 2013; Gubbi et al. 2013), as specified in the user interface module, and defines the game itself. As this framework presents the interconnectivity of Serious Games and the Internet of Things, the application must be either be a game, have elements of gamification or use game technology.

4.2.8.1 User Interface and Game

An argument can be made for the removal of the user interface module, as it is possible to create Serious Games that integrate with the Internet of Things with no interface at all. An example of this could be a game that is played with buzzers. The buzzers instruct play and react to a player’s physical location. The modular approach allows future applications to remove the user interface module without interfering with the stated layers. Finally, this framework benefits more than solely Serious Games. Gamification and games can both benefit from this framework, as it is the integration with the Internet of Things that holds value.

4.3 Chapter Summary

This chapter presented the proposed modular and interconnected framework for integrating the Internet of Things with Serious Games, a product defined as Smart Serious Games. This framework groups related modules into layers and illustrates the interconnectivity in a top-down style. As the proposed framework is modular, it is adaptable, allowing future research to rearrange modules or replace them to suit for service specific needs. Alongside the framework, this chapter discusses the requirements that must be met when defining a framework of this nature. The included requirements were formed based on the undertaken literature survey, which identified a lack of frameworks for non-service specific applications. The developed framework forms the foundation for the following chapter, which details the case study and the research surrounding it. The following chapter validates the proposed framework by introducing the thesis' case study.

CHAPTER 5 – VALIDATION OF THE PROPOSED FRAMEWORK

5.1 Introduction

This thesis has described Serious Games, the Internet of Things, and defined the technological integration from a software and networking perspective. To validate the developed framework this thesis measures student engagement through Smart Serious Games as a case study. This chapter begins by introducing the bespoke version of a hybrid wireless sensor network topology, and a bespoke framework, utilised for developing the Smart Serious Games as part of the case study.

Data is a fundamental element of Smart Serious Games as it allows for game progression and user feedback. Intrinsic and extrinsic sensor networks and gameplay generates meaningful data that will affect gameplay. Unprocessed data serves little use to Smart Serious Games. The analysis and conversion from raw data to meaningful outcomes occur through data algorithms. As such, this chapter proposes a computer algorithm based on class attendance and punctuality in addition to questionnaire scores obtained directly from the participants on a weekly basis. The calculated sum serves as data points that can be utilised in games, gamification, serious games and Smart Serious Games. Furthermore, this chapter introduces the Internet of Things as a utility of measuring real-world environmental effects on student engagement.

Finally, this chapter presents and justifies the process this thesis took for developing the Smart Serious Games and details the game architecture.

5.2 Application of a Smart Serious Game Topology

The proposed topology aims to measure students' engagement with their programme by sourcing data from the physical world that affects the virtual one presented in the game. Figure 5.1 illustrates the proposed topology for the application of this thesis. Further information on the Smart Serious Game for measuring student engagement can be found in the sections below within this chapter. Games that utilise environmental and user data, sourced through smart devices and services to affect gameplay, could benefit from the proposition.

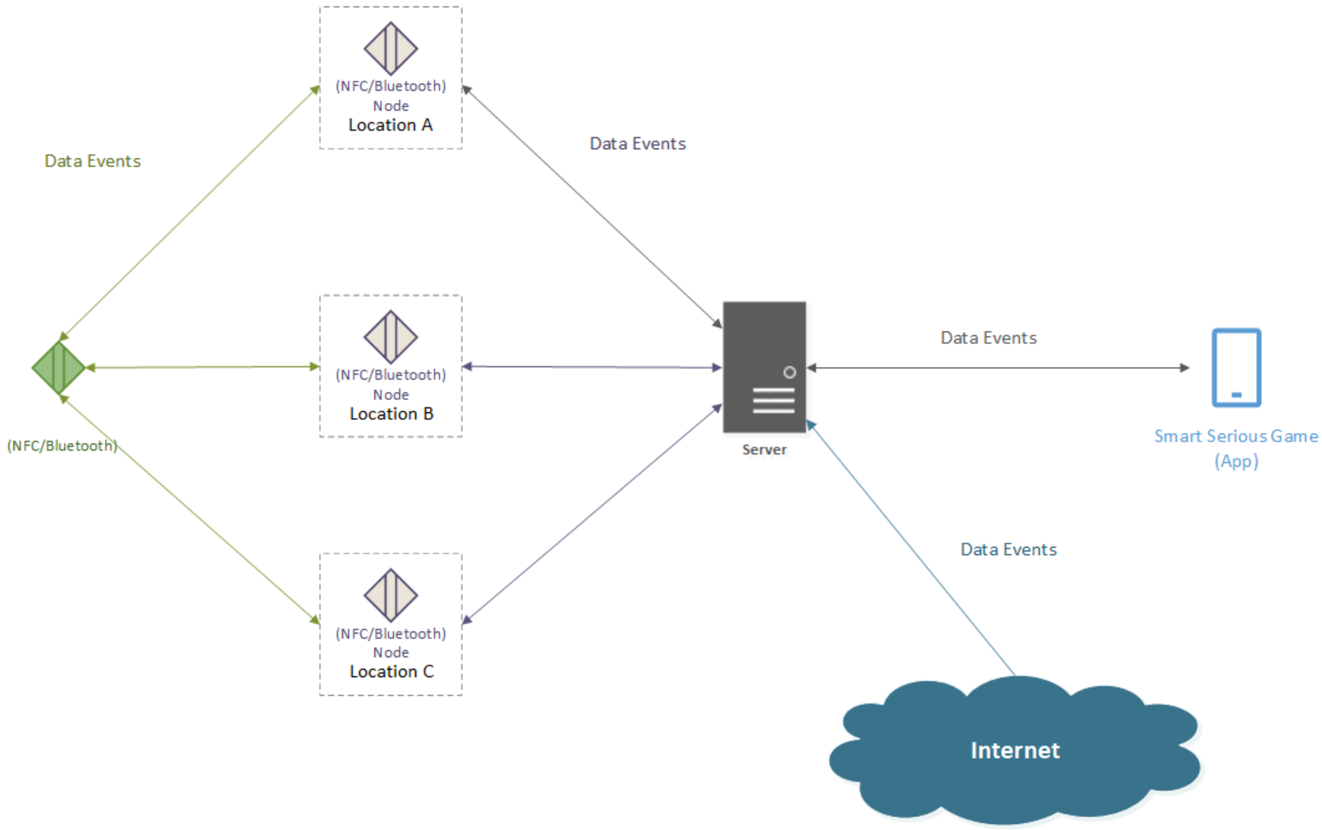

Figure 5.1 Topology for the proposed Smart Serious Game solution

The elements of the proposed topology are outlined as follows, and their purpose explained.

1) *Bluetooth Receiver:* A Bluetooth Wireless Sensor Network is chosen for this topology instead of Radio-Frequency Identification (RFID), to eliminate the need for a reader device (Atzori et al. 2010) and create a more pervasive experience. It is

important to aim for a pervasive solution as research has proven an increase in participants' immersion for such solutions (Lv et al. 2015). To track players' location and attendance smartphones will be utilised for their Bluetooth capabilities. It is the same devices that will be running the proposed Smart Serious Game, extending the mobility and accessibility of the solution.

2) *Location Nodes*: These nodes will utilise the campuses extended Wi-Fi coverage, relaying information to the central server, located on campus. In the proposed Smart Serious Game, registering check-ins into locations across the campus will be achieved through nodes with Bluetooth capabilities. Raspberry Pi has been chosen to represent the nodes in the proposed system due to their autonomous connection to the Internet and embedded Bluetooth capabilities. Cloud computing was considered for this project but was not deemed vital in determining the effectiveness of the proposed framework, found in Chapter 4.
3) *Web Datasets:* Datasets will be comprised of real-world data in an attempt to correlate daily events with players' behaviour. If such a correlation can be achieved, the game will be able to better predict behaviour and encourage engagement in advance in future works. An example of web datasets to be used include solar cycle, weather and others. The number of datasets to be included greatly relies on the availability of open source data.
4) *Hosted Server:* For data storage, this proposed topology opts for a hosted server, maintained and managed by Liverpool John Moores University. Utilising the university's server allows this research project to store data securely. The server must be hosted and not local, for client access from any network with Internet connectivity.
5) *Data Events:* This topology considers the data flowing through as data events. This is because all data generated and utilised (check-in, weather) will cause an immediate

effect to the game. E.g. Reactive response: unlock inventory item for customisation of avatar, Proactive response: encourage players on a rainy day. Figure 5.1 notes a bi-directional relationship between all components of the suggested topology. By utilising bi-directional communication, clients can receive confirmation of a check-in in the form of a notification.

The stated elements of the proposed topology are service specific to our proposed application of a Smart Serious Game that monitors student engagement by utilising the physical world for progressing in a game in a virtual setting. Smart Serious Games or other applications can draw inspiration from this topology and extend it or replace its elements with technologies better suited for their project.

5.3 Application of Proposed Framework

The proposed framework is structurally identical to the application framework for this case study, as seen in Figure 5.2. When comparing the Figure 5.2 with Figure 4.1, it becomes apparent that this framework includes protocols, technologies and programming languages that are application specific. In detail:

1) *Sensing Layer*: This thesis's proposed application incorporates extrinsic sensor networks to correlate student behaviour with traffic and weather. It achieves this through a hybrid wireless sensor network and Web API.
2) *Networking Layer*: For the proposed application, cellular networks such as 3G, 4G and others are considered, as the game requires internet connectivity to operate. The communication protocols module pinpoints the underlying protocols that are utilised within the networks. Bluetooth Low Energy (BLE) enabled applications could benefit from specifying the Generic Application Profile (GATT) protocol within this module. An argument can be made for the placement of this module in the proposed

framework, as the application would need to access the networking layer in order to communicate with the middleware. Though this is true, for readability this framework focuses on one-directional data flow. Aside from this, networking is expected to be essential for an online game, and therefore its placement can be presumed.

3) *Middleware Layer*: The proposed application utilises a cloud-based broker (Cloud MQTT) that handles messages sent from an intrinsic sensor network to the server. This layer also includes the server end module, which specifies web-hosted PHP scripts and local scripts executed through Node-RED, a Node JS visual scripting tool, used for combining Internet of Things technologies. These technologies can vary based on the application needs, for example, a hosted web-app and database alone may suffice for other applications. Furthermore, the application translates data from the Raspberry Pi to game points and quantifying student engagement using data algorithms. Game mechanics are utilised for player progression and game progression.

4) *Interactive Content*: The application utilises a user interface to relay engagement through an avatar and inform players of their behavioural patterns in relation to events in the physical environment. Furthermore, the user interface provides a visual representation for menus, the avatar gallery and more. Additional details on the application are presented in Section 6.2

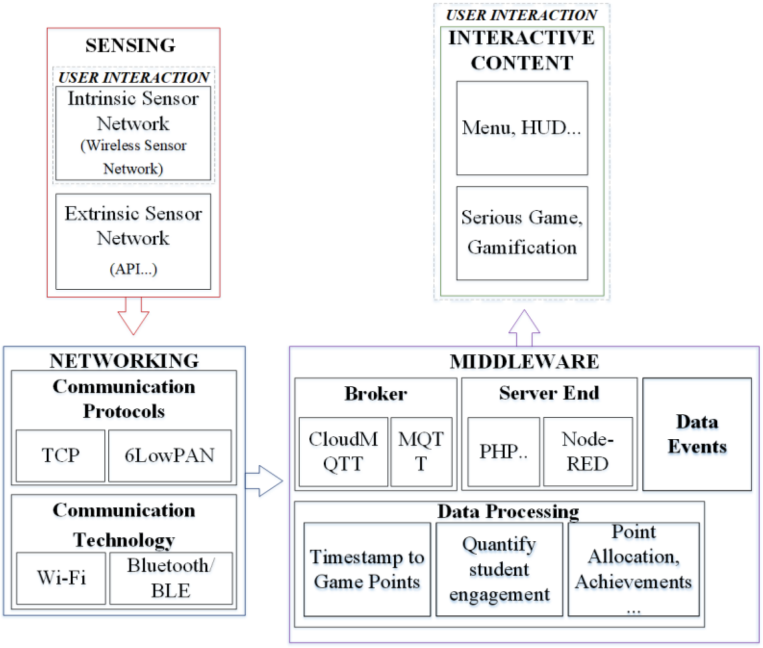

Figure 5.2 Application of the proposed framework for combining the Internet of Things and Serious Games.

5.4 Quantifying Student Engagement

Section 2.2.2 details the research relating to serious games and student engagement and identifies the measure of Student Engagement through qualitative feedback acquired from questionnaires.

Further to research publications, instruments such as the UK Engagement Survey Pilot attempt to measure student engagement by presenting a series of questions. Directly adding a questionnaire of such scale into a game presents a key hurdle in its length. A game that measures students' engagement by accounting for their actions in the physical world as a representative of their behavioural engagement must condense the aforementioned questionnaires. Players should not feel that the game is straining their ability to study in any capacity. The lengthy questionnaires measure student engagement once per participant, conventionally at the end of a term or academic year. If a game is to measure student engagement on a weekly basis, the questionnaire that aids in this measurement process must be adapted for the service. This study reduces the questionnaire to ten questions that target the measure of behavioural, cognitive and emotional elements, based on the literature survey. This section presents further information on the questionnaire and the integration of it in a Smart Serious Games.

The Internet of Things makes it possible to quantify elements of student engagement, particularly behavioural, by monitoring class attendance and punctuality. Monitoring attendance and punctuality is not a new measure of student engagement, however obtaining the data through a wireless sensor network generates accurate data, captured in a less invasive manner. Traditional attendance monitoring systems involve pen and paper, which is susceptible to student forgery. Recent systems include Radio-Frequency Identification (RFID) cards and receivers; however, this is still more invasive than true Internet of Things solutions and can disrupt the class flow.

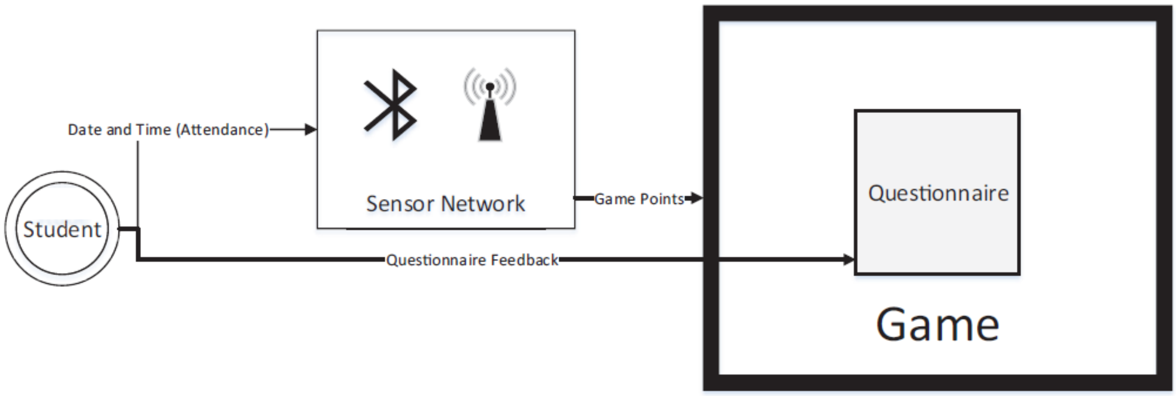

Figure 5.3 Illustration of the model used for quantifying student engagement

Figure 5.3 presents the model for monitoring student engagement using sensor networks and self-reflection instruments integrated in-game. Figure 5.4 displays the pseudocode relative to attendance monitoring and the point allocation system that turns timestamps to meaningful data. In summary, wireless sensor networks track student attendance and punctuality and produce a timestamp once the target device is identified within timetabled sessions. The timestamp translates to game points after determining how punctual a student was for each lecture or practical session they attended. Appendix 1 presents a breakdown of the game point allocation based on attendance and punctuality. In the following chapter, Figure 6.1 illustrates the programming sequence relative to obtaining the timestamp from the wireless sensor network.

```
----------------------DETERMINE ATTENDED WEEKS THAT REQUIRE POINT ALLOCATION----------------------
IF 'New Week'
        FOREACH 'Week that has not been calculated'
                'Check for recorded attendance against student timetable'
                IF (Attended)
                        'Add attendance and punctuality to list for score allocation'
                ELSE
                        'No attendance in the week, provide a score of 0'
ELSE
        'Go to main game screen'


----------------------POINT ALLOCATION FOR ATTENDED WEEKS-------------------------------
FOREACH 'Attendance in list'
        IF 'Attended within first five minutes'
                'Allocate top punctuality and attendance marks'
        ELSE IF 'Attended between first five minutes and twenty minutes'
                'Allocate top attendance marks but deduct two points from top punctuality marks'
        ELSE IF 'Attended between twenty minutes and an hour'
                'Allocate top attendance marks but decuct three points from top punctuality marks'
        ELSE
                'Deduct three marks from top attendance points and provide one point for punctuality'


----------------------ALGORITHM STEPS------------------------------------
STEP ONE'Weekly attendance and punctuality scores'
        'Obtain total score from questionnaires'
        'Calculate sum of two values then divide by two'

STEP TWO'Divide sum by the highest possible sum a student could achieve'
        'Divide by 100 to obtain percentage'
        'Round - Ceiling the value'
```

Figure 5.4 Pseudocode of data management for algorithm and algorithm key steps.

Game points form the value of engagement a student receives on a weekly interval from the game. The engagement value is produced through data algorithms, detailed in Section 5.5. In summary, the data algorithms account for game points obtained through the sensor network and self-reflection points obtained from questionnaires embedded in-game.

The scoring system for the questionnaire follows the principles set by the findings of the literature survey detailed in Section 2.2.2, that utilise the same means for obtaining a measure of student engagement. In detail, the questionnaire provides a rating of 1 – 4, masked in selection options of "Strongly Agree", "Agree", "Disagree", and "Completely Disagree", to questions that monitor distribution, effort, contribution, concentration, interest, boredom, satisfaction, happiness, desire, and strategy. The structure of the questions ensures that point 4 is the highest level of engagement. Appendix 2 presents the questions used for this thesis.

5.5 Measuring Student Engagement

The measure of student engagement will be visualised in-game as a score, where a high value equates to high student engagement levels. Presenting a summary score to students allows them to understand their own engagement easily and represents student engagement in the game as a score, where scores allow for game progression and game achievement.

The student engagement value is calculated by accounting for class attendance, punctuality, and the self-reflection of students, gathered by in-game questionnaires. Activities (attendance and punctuality) performed in the physical world provide a quantitative score each time they are completed. Students that complete a streak of game objectives will receive further rewards. For example, a student that attends all classes in a week will receive an unlockable and collectable achievement badge in game.

In detail, attending a timetabled class is an objective of the Smart Serious Game, which awards five points. Attending all classes in a week is a separate game objective that rewards an achievement. This method of scoring and rewarding provides a point balance between those who are engaged and those who are disengaged. It is pivotal that the game adequately rewards behavioural engagement, to stimulate cognitive and emotional engagement. Section 5.5.2 provides further detail on data points and the methodology used.

5.5.1 Engagement Simulation

This thesis undertook a form of data simulation to identify the range of scores between engagement levels, and to determine the best data algorithm for aggregating the total of game points. All data simulation was performed utilising spreadsheet software. To begin with, data obtained from Web APIs regarding traffic, weather and sunlight duration were exported into the spreadsheet. A timetable copy of an active programme at Liverpool John Moores University was utilised, providing the number of classes in a week and their respective locations. At this stage, three personas were developed.

Each persona represented a point in the spectrum of student engagement, therefore producing *disengaged*, *engaged* and *neutral* persona. Game point straining simulation was performed over two hypothetical weeks. The first week utilised assumptions based on each persona. The *disengaged* persona achieves around 20% of weekly attendance and punctuality points, and scores low on self-reflection, the *neutral* persona obtains 88% of attendance and punctuality points with a 50% score on self-reflection, whereas the *engaged* persona is allocated with top scores for all components.

These assumptions tested resiliently the game point mechanism and the data algorithm for a balance in scores. By manipulating the points of reward through multiple iterations of calculations with the data algorithm, a fairer score was produced, and data anomalies were solved, ultimately changing the data algorithm itself. Utilising spreadsheet software proved extremely useful for defining a strong data algorithm before application or game development, reducing data complications at the experiment stage.

Simulating based on persona assumptions provided the foundation for the fair in-game rewards, however when taking this data algorithm and points system to real students, further anomalies could occur. To test this, prior to the development of the game, all scores for each persona were randomised for the second week utilising embedded functionality provided by the spreadsheet software. For the second randomised week, the engaged and disengaged persona produced disengaged scores whereas neutral remained within a neutral score range. This occurred as attendance points were allocated by picking a random number (between 0 and 10), directly affecting the respective engagement scores per persona. Appendix 1 illustrates the spreadsheet and the values produced for each week, where an engaged factor is symbolised with white, neutral with grey and disengaged with black.

As aforementioned, this thesis utilises attendance and punctuality to quantify student behavioural engagement, therefore the results produced indicated no preliminary issues. By utilising spreadsheet software and data algorithms, it is, therefore, possible to detect data anomalies before the development cycle begins, aiding in reducing it.

5.5.2 Data Algorithms for Measuring Student Engagement

This thesis developed a data algorithm to calculate the sum of values obtained from intrinsic wireless sensor networks and self-reflection questionnaire in the game.

As stated in Section 5.3, the data algorithm for representing student engagement in the game is the product of iteration. Initially, a data algorithm was defined that represented student engagement by averaging the value of self-reflection with the value of attendance and punctuality, thus producing a mean value for conventional and new methods of student engagement measure. This thesis does not attempt to replace self-reflection as a means of measuring student engagement but proposes an overlay with the use of Smart Serious Games. Therefore, the average principle remained in the final iteration of the data algorithm.

$$En = \left[\frac{1}{2}(Ca + Cp + \frac{Wt}{d})\right] \qquad (5.1)$$

Equation 5.1 illustrates the first iteration of the engagement (*En*) data algorithm, which represents the total engagement score achieved and forms the core measurement of achievement in-game. *Ca* and *Cp* are the weekly total of game points amounted by class attendance and punctuality, respectively. *Wt* symbolises the questionnaire weekly total scores, as calculated in Equation 5.2. In detail, averaging the sum of game points achieved through the sensor network and the weekly total *Wt* score divided by the number of timetabled days for students' results in *En*. The algorithm divides by two, as it considers *Ca* and *Cp* as one factor because they require student presence for positive scoring. This thesis uses the Internet of Things to measure a percentage of behavioural engagement, as the literature survey states presence as an element of behavioural engagement. The self-reflection questionnaire accounts for the remaining percentage of behavioural engagement, as the questions 1 to 4 in Appendix 2 state.

It is possible for the Internet of Things to provide a measure of cognitive and emotional student engagement, however quantifying these elements would require intrusive technology, such as head scanners or video cameras. Extrinsic sensor networks may produce an indication of emotional and cognitive student engagement by monitoring if a student chooses to attend, with severe weather conditions, high traffic congestion, or out of scheduled time. Further research needs to investigate if any possible correlation is required.

$$Wt = \left[\frac{Cs}{2} + \frac{Cs}{2}..\right] \qquad (5.2)$$

Wt was initially calculated by averaging the total class score *(Cs)* from student and academic and summing up the value of average class scores obtained through a timetabled week, as a form of validation. The final iteration of the data algorithm removed this calculation as this algorithm requires students to self-reflect on a daily basis, a workload deemed excessive on both entities by academics and post-graduate students, after carrying out preliminary tests with a group of five academics and five postgraduate students. Furthermore, the literature survey into student engagement discovered similar studies obtain scores solely from students, at infrequent intervals. This algorithm is valid for future studies that require an average value from self-reflection instruments of two parties.

The final iteration of engagement *(En)* is the sum of Score *(S)* divided by the highest possible score *(He)* each student could achieve. As the obtained value is a percentage, the sum is multiplied by one-hundred. Using a percentage of student engagement as game points eliminated unfair scoring for students with more demanding timetables. Elaborating, the initial algorithm would produce double the sum for students with identical monitored levels of student engagement with ten timetabled classes as opposed to five. Utilising a percentage rectifies this issue.

Furthermore, the final iteration of the data algorithm *En* considers the persona of a student that prefers distance learning, through virtual learning environments. Previously, attendance and punctuality scores produced the majority of game points. To elaborate, where a student receives five points for attendance and an additional five for punctuality, in a week of five classes, they could achieve fifty points. If the same student measures as engaged through the questionnaire they would accumulate an additional forty points. However, the game points they would receive for the week would amount to forty-five. In addition, by calculating the average, the algorithm considers university procedure, which states a student must attend at least one class a week. Mathematically, a student that attends one class but self-reflects themselves as engaged could achieve a score of twenty-five game points and progress well through the game.

This algorithm, however, presents a limitation for use in games. Games rarely present scores or points as decimals, therefore the algorithm utilised round ceiling to produce a whole number, in favour of the student as presented in Equation 5.3.

$$En = \left\lceil 100\left(\frac{S}{He}\right) \right\rceil \quad (5.3)$$

Expanding on the aforementioned algorithm, score (*S*) is the sum of calculated attendance *(Ca)*, calculated punctuality *(Cp)*, and questionnaire self-reflection, divided by 2. Dividing by 2 obtains the average value of the Internet of Things generated score and electronic questionnaires. The final version of the *En* data algorithm removes the division of self-reflection score by the timetabled days, as the frequency of questionnaires was reduced to weekly intervals. Equation 5.4 details the equation for *S*.

$$S = \left\lceil \frac{((Ca + Cp) + Wt)}{2} \right\rceil \quad (5.4)$$

Highest engagement (*He*) is a sum relative to a student as it considers the number of weekly timetabled classes. In detail, *He* comprises *Ga*, *Gp*, *Tc*, and *Hqs*.

- *Ga*: A static game point allocated by the game developer for attending a class.
- *Gp*: A static game point allocated by the game developer for punctuality with a class.
- *Tc*: The number of weekly timetabled classes for a student.
- *Hqs*: The highest value produced from the self-reflection instrument.

Therefore, the highest possible engagement score is the best attendance score added to the best punctuality score for the week, the sum of which is added to the highest possible measure of questionnaire scores as Equation 5.5 illustrates.

$$He = \left[\frac{(Ga * Tc) + (Gp * Tc) + (Hqs)}{2} \right] \quad (5.5)$$

The presented algorithms are service specific to the case study of this thesis, and therefore would require further consideration before being applied in similar case studies or adapted for future works. To further the effectiveness of this engagement data algorithm, this thesis details its abstract elements and considers the scalability of variables.

Fundamentally, the algorithm calculates the percentage of an average and rounds up this sum to a whole number. The average accounts for two variables, as this research's case study includes attendance and punctuality points against self-instrument points. Before increasing the variables in the *S* algorithm, no numerical advantage must be given to points obtained from sensor networks. In detail, if future work accounts for the length of time a student remains present in class and assigns points for this, the sum of *S* would be greatly influenced by points obtained from sensor networks, suppressing the role and importance of self-reflection. To avoid this, calculate the average of a set number of sensor network variables, and utilise this sum to obtain an average between sensor network points and points sourced from self- reflection instruments. Equation 5.6 illustrates the above.

$$S = \left[\frac{(\frac{V1+V2+V3+V4}{Numvr}) + Wt}{2} \right] \quad (5.6)$$

Including the scalable iteration of *S* into *En*, would produce a whole number that is the percentage of an average of two elements, regardless of the variables per element. Therefore, *En* is a data algorithm that is application neutral, when altering the dependant *S* algorithm to a scalable iteration.

5.5.3 Dynamic Difficulty Adjustment

The previous section details the computer algorithms utilised for representing the measure of student engagement in-game. Notably, no mention of Dynamic Difficulty Adjustment algorithms was made, though they are frequently used in Serious Game research projects that involve computer algorithms.

Dynamic Difficulty Adjustment alters gameplay by parameterising aspects that directly contribute to a game's difficulty, with research including but not limited to, Artificial Intelligence (Hunicke & Chapman 2004). Key research in the academic field includes the investigation by Liu et al. (2009) into utilising Dynamic Difficulty Adjustment through anxiety-based feedback, monitored user anxiety and performed affected-based changes in real-time gameplay. Anxiety was monitored to determine whether players were finding gameplay challenging. When the gameplay became too challenging, Dynamic Difficulty Adjustment would adjust the difficulty. After experiments, the study noted improved user performance, better user satisfaction and a better level of gameplay challenge. The research by Liu et al. (2009) presents an example of quantifying player emotion and beliefs through a data algorithm.

Liu et al. (2009) noted a form of improvement in the respective examined case, therefore this project excluded Dynamic Difficulty Adjustment as its inclusion threatened to inflate the engagement scores obtained from the Smart Serious Game, skewing the validity of the measure against conventional measures of engagement.

5.6 Chapter Summary

This chapter presents the application of the proposed framework and the case study of this thesis; measuring student engagement through Smart Serious Games. Topics surveyed include student engagement and findings in relation to student engagement and Serious

Games. This chapter also introduces a computer algorithm for measuring student engagement based on an average of their attendance, punctuality and self-reflection. This data algorithm caters to Serious Games, gamification and edutainment as it utilises game points to portray results. The Internet of Things acquires a measure for elements of behavioural engagement data that subsequently are correlated with real-world events. The results of this correlation aim to encourage and alert students to facts regarding their engagement. Finally, this chapter presents the use of data simulation for validating the data algorithm, using personae, and spreadsheet software. The following chapter details the development of the Smart Serious Game and all the accompanying systems.

CHAPTER 6 – SYSTEM DEVELOPMENT

6.1 Introduction

Chapter 6 details the technological development completed for developing the respective Smart Serious Games. This chapter focuses on the core elements of programming, interface design and technology interaction, providing a foundation for future research projects that include the development of a Smart Serious Game. An element that is not included in this chapter is the reasoning for the questionnaire design, as Section 5.4 justifies it. Furthermore, this chapter rationalises the choice of technologies utilised in the Smart Serious Games, considering cost, development time and application.

This chapter breaks down the development of all system elements, from the attendance monitoring system to the Smart Serious Game and accompanying web portals. Due to data protection issues, this thesis cannot access the current electronic registration data recorded by Liverpool John Moores lecturers, as it provided by third party software. Therefore, this thesis developed an attendance monitoring system.

This thesis adopted the agile development cycle to ensure the Smart Serious Game was completed within the project's timeframe, whilst attempting to remove all critical bugs from the final prototype before experimentation through frequent testing.

6.2 Programming the Internet of Things

As this thesis combines the Internet of Things with Serious Games, the programming requirements for each technological area differs. Developing for the Internet of Things requires an understanding of networking, middleware and scripting languages. Additionally, development must evaluate scalability and network load, in accordance with the topology requirements. The following section focuses on the development of software for the nodes of the monitoring system, the programming for data storage and validation, and the programming for obtaining appropriate data from extrinsic sensor networks, provided by Web API.

6.2.1 Node Programming

Section 5.3 defines nodes in the proposed topology as remote autonomous nodes with interchangeable locations. This study chose the Raspberry Pi 3 for nodes due to their low power, portable and affordable nature. Furthermore, the Pi 3 includes onboard Bluetooth and Wi-Fi capabilities, eliminating the need for purchasing and configuring additional adapters. This programming in this section is not confined to the Raspberry Pi 3 and can be adapted with minimum changes to suit other microcomputers such as the Arduino.

Fundamentally, the nodes operate on Linux, specifically Ubuntu Mate[4]. This operating system provides all the extensive support of Linux, with minimum bloatware[5]. The automated attendance system utilises shell scripts for execution at startup and Python for all following scripts.

The nodes serve two functionalities; discover relevant devices on a set interval of two minutes and listen for a request to change the current location of the node. Figure 6.1 illustrates the key programming structure for nodes.

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[4] https://ubuntu-mate.org/ - Ubuntu Mate – Accessed 27/03/2018
[5] https://dictionary.cambridge.org/dictionary/english/bloatware - Bloatware definition - Accessed 27/03/2018

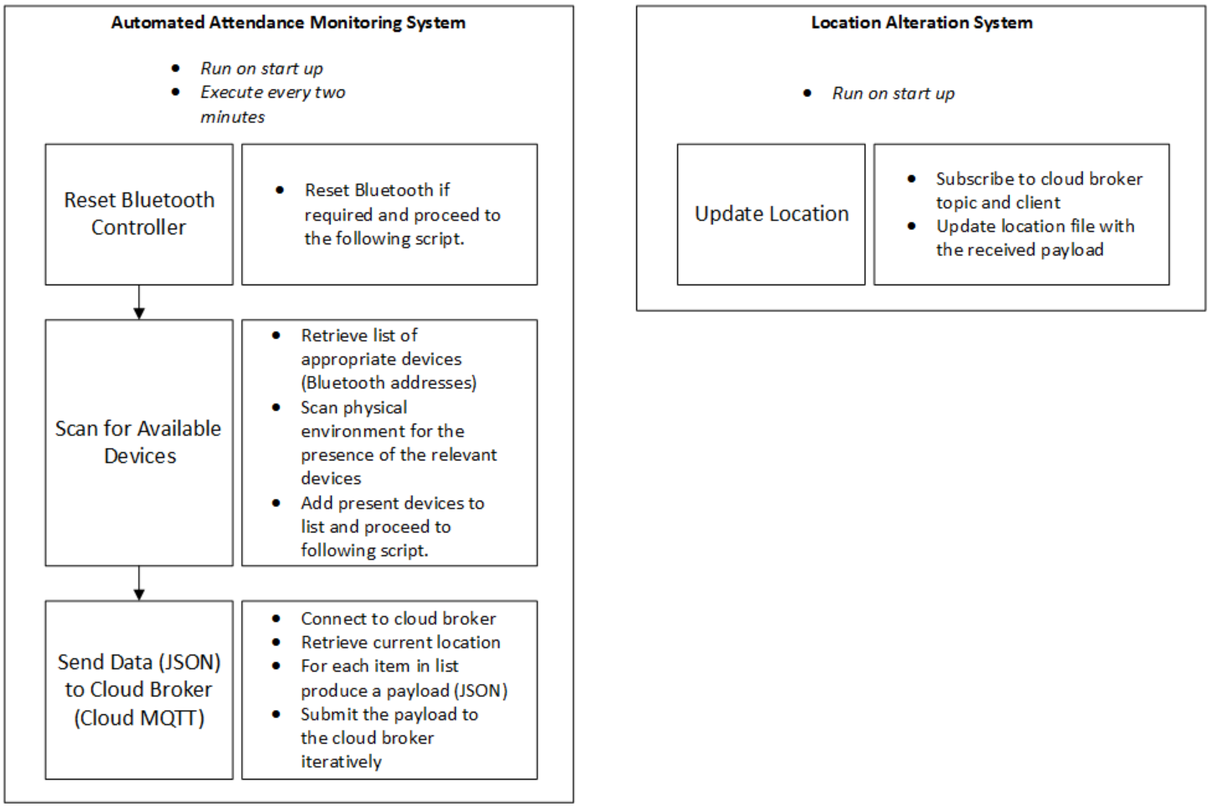


Figure 6.1 Programming Structure for nodes

In detail, the first system, labelled *Automated Attendance Monitoring System*, is executed in console from a batch script at startup. The shell script calls the final script, which determines the interval of execution; however, the sequence of execution follows the pattern illustrated in Figure 6.1. The first script attempts to initiate the Bluetooth seeking capabilities of the node, if this fails, the script resets the Bluetooth controller and re-attempts the initiation. The Bluetooth controller on the Pi 3 did often need resetting, especially after several system iterations. Other hardware may not require such functionality, supporting the system's modular approach of development.

The second script in the *Automated Attendance Monitoring System* contains the core mechanism, as it scans for relative and known devices, and dependant on their status adds them to a list of present devices. By known, this thesis stipulates a device that has actively scanned for other devices at least once, whilst the node was advertising. The developed solution does not require a full pairing process. If there are no present devices, the process ends here, emitting the final script. The process will restart after two minutes, to update the presence of known devices. If there are one or more present devices, the final script executes.

The final script in the *Automated Attendance Monitoring System* connects to the cloud broker then loops for the number of present devices. Each iteration, if more than one device is present, obtains the Bluetooth Address of the present device and the current location of the node, to generate a JavaScript Object Notation (JSON) structured payload. The payload publishes to a specific account and a specific topic. This ends the process of the *Automated Attendance Monitoring System* until it restarts in two minutes time. The process can be fully terminated by powering off the node.

The *Location Alteration System* runs simultaneously in a separate console, triggered on startup by a shell script. The script proceeds to connect to a cloud broker account and subscribes to a topic. The script remains idle listening on the subscribed topic until a message is received. The messages originate from the academic portal, detailed in Section 6.3, and contains the name of the current building. Once a message is received, the script overwrites a text file containing the current location. The process then terminates and does not restart until the next message.

Both programmed node systems present a foundation for remote nodes in a hybrid wireless sensor network topology. The application of such systems extends beyond Serious Games, games or game technology.

6.2.2 Middleware Programming

The middleware module of the proposed framework comprises of the intercommunication between sensor networks and game technology and consists of three key elements; the cloud broker, a programming tool, and hosted scripts for data validation and data storage. This thesis utilises Cloud MQTT[6] for the cloud broker, Node-RED[7] for the programming tool and a hosted area accompanied by a hosted database, provided by Liverpool John Moores University.

Cloud MQTT provides free cloud brokerage, limited to 10 connections and a 10Kbit/s transfer rate. This thesis adapted the solution to cater for the restrictions set by the cloud broker. Firstly, the payload transferred to and from the cloud broker is minimal, and contains only one or two elements, adhering to the limited transfer rate. Minimising the payload presents further benefits such as reduced network demand and latency. This project used a single account to handle all nodes and their systems. The account holds twelve topics, two per active node. Table details the topics and their respective nodes.

[6] https://www.cloudmqtt.com/ - Cloud MQTT – Accessed 27/03/2018
[7] https://nodered.org/ - Node-RED – Accessed 27/03/2018

Type	Pattern
topic	pi5 - getLocation5
topic	pi5 - setLocation5
topic	pi6 - getLocation6
topic	pi6 - setLocation6
topic	pi4 - setLocation4
topic	pi4 - getLocation4
topic	pi3 - setLocation3
topic	pi3 - getLocation3
topic	pi1 - setLocation
topic	pi1 - getLocation
topic	pi2 - getLocation2
topic	pi2 - setLocation2

Table 6.1 List of topics per node

For each node, the *getLocation* topic transmitted the location of a present device, whereas the *setLocation* topic transmitted the present location of the node. Cloud MQTT provides scalability, but at a subscription cost. Other cloud broker vendors include IBM and Amazon Web Services (AWS) from Amazon. The choice of cloud broker has no effect on the composition of the proposed framework in Section 4.2, nor does it affect the results of the measure on Student Engagement.

All messages sent to and from the cloud broker interacted with the Node-RED, a programming tool developed by IBM and based on Node.JS, which allows for runtime execution. Node-RED utilises visual scripting to reduce development time, labelled as flows. This project incorporated Node-RED as it offers a free solution to developing a scalable

Internet of Things system, with minimum development time. Node-RED runs locally but receives and transmits messages to the cloud broker, and triggers hosted scripts.

For the purpose of this case study, each node had a separate palette, detailed in Figure 6.2.

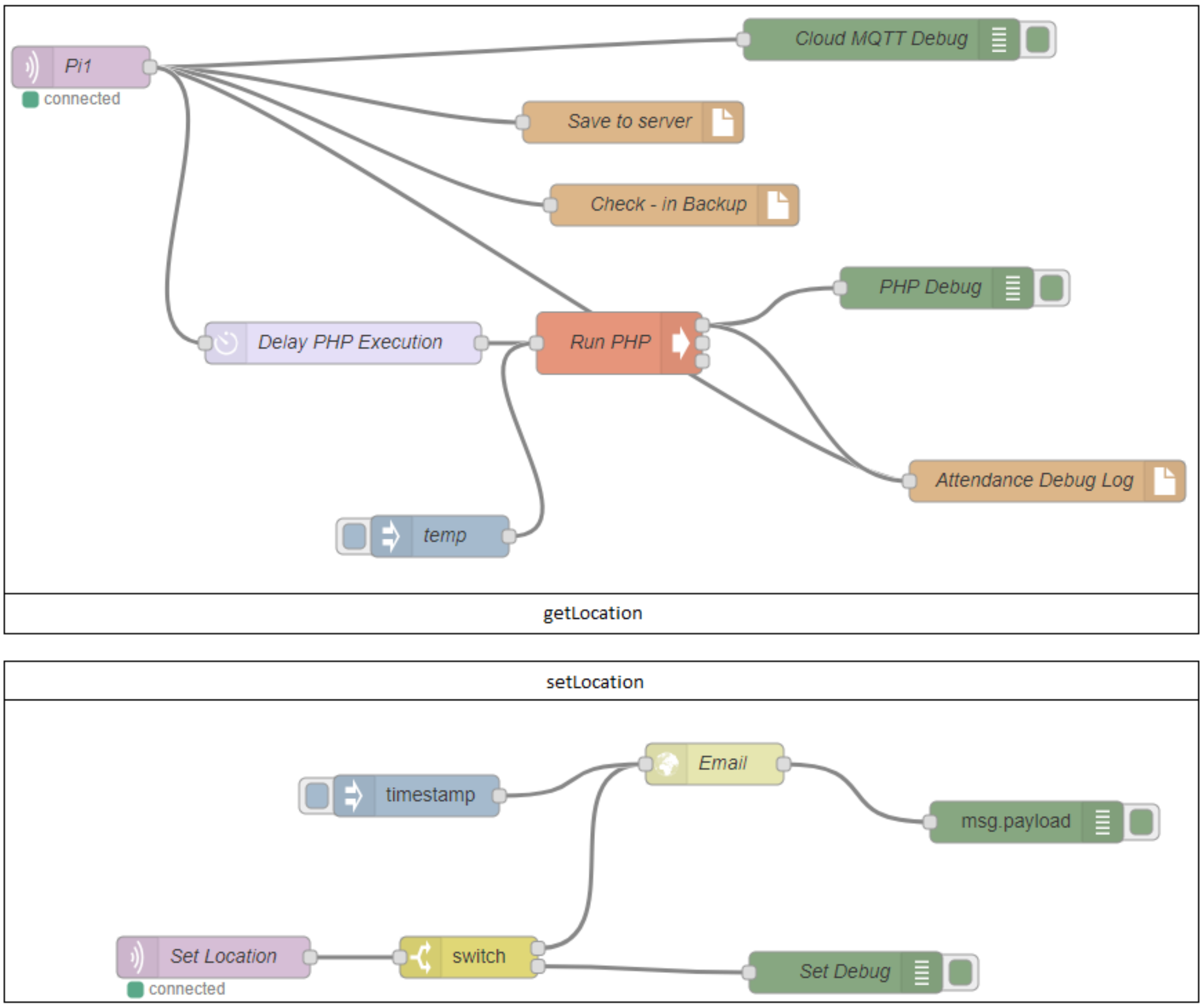


Figure 6.2 Example of flow for a node

The top half of Figure 6.2 illustrates the visual code developed for receiving the Bluetooth Address and location of a present node. The sequence flows from left to right. The initial node connects to the cloud broker and listens for messages from a specific user and topic, in this example the first wireless network node. Upon receiving a message, the brown nodes generate local and hosted copies of the data for debugging purposes, and to be read by the hosted script responsible for data validation and storage. As seen in Figure 6.2, a node delays the execution of the hosted PHP script by two seconds. The delay provides enough time to overwrite the relative file that stores the respective Bluetooth Address and location iteratively. As an alternative, it is possible to feed information directly to PHP through the cloud broker. The use of a local file does not impede the measure of Student Engagement obtained from the system. The final key node in the *getLocation* section triggers the hosted PHP script, responsible for validating presence against a student's timetable, and inserting data into the database, whilst preventing duplicate entries.

The *setLocation* section contains a node for receiving and publishing messages to the cloud broker. The switch node to the right determines the flow of events. If the payload message contains the words "Location updated" it will send an email to the academic staff responsible for the remote network node, otherwise it will do nothing, as it is the network node's responsibility to set the location. A payload message will only state the aforementioned phrase when the network node updates the location file and transmits the message to the same account and topic through the cloud broker. This feature provides academic staff with feedback when a location is changed through the academic portal, detailed in Section 6.3.

The hosted area and database form the final key element of the middleware. As mentioned above, the hosted area and database were provided by Liverpool John Moores University. Without the hosted area, the Smart Serious Game and the portal counterparts could not have materialised. The Smart Serious Game requires players to act in the physical environment to progress, causing the game to require portability from a networking perspective. Therefore, a hosted area allows a user to log in and obtain their data from any location that has Internet connectivity. Furthermore, the production of web portals for academics and students that do not interact with the game requires a web-hosted area. The same criteria affect the decision to utilise a hosted database.

The hosted database utilises MySQL. The use of MySQL derived from the availability that the university had, but in no way affects the framework or the integrity of the measure of Student Engagement. An SQL database or others would suffice and produce identical outcomes.

6.2.3 Extrinsic Network Programming

The development for the integration of extrinsic networks relates to the middleware section, however, due to its nature and specific flow style, this thesis presents it in its own section. Extrinsic sensor networks feed data to Node-RED through API. However, it is Node-RED that determines when an API call should be triggered. Figure 6.3 presents the flow for obtaining data from two API sources; weather data from the Met Office, and traffic data from HERE. The top left node schedules an API call to run every weekday at one in the morning. This allows the system to retrieve the full twenty-four-hour forecast for the day. If an error occurs it formats the payload appropriately, then emails the author for debugging purposes.

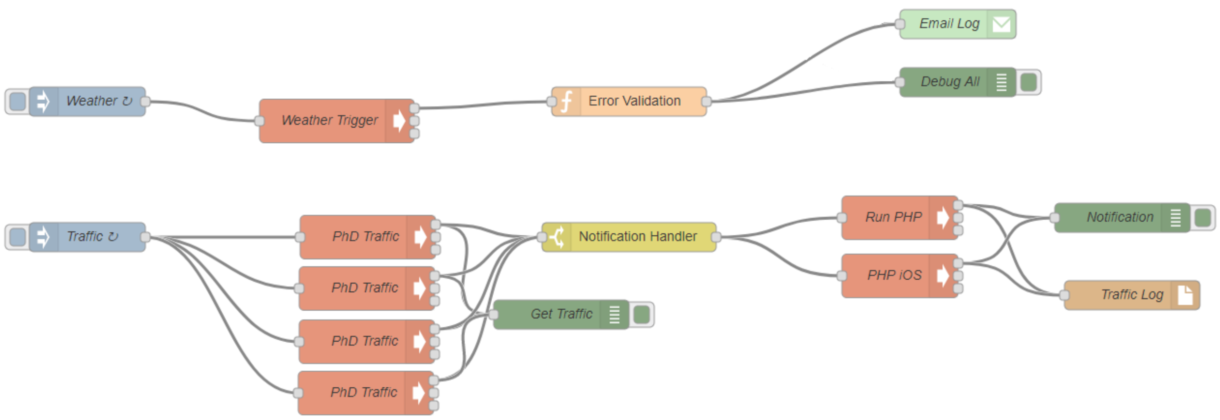


Figure 6.3 Flow for API

The traffic API runs on a five-minute interval, every weekday, from eight in the morning until six in the evening. This interval allows the system to cover all timetabled sessions for each relevant programme of study, and to obtain the traffic an hour before the start of a session. Figure 6.3 illustrates four trigger nodes for executing four different hosted scripts.

The system has been developed on a one to one basis, where one script checks the timetable for each related programme of study. This provides scalability and allows concurrent processes to run without the need for a complicated programming solution. After the data is stored, the traffic congestion is analysed for each student on the programme. If the congestion time is higher than the average in comparison to a student being late or absent, a notification alerts them to current traffic conditions. Other API sources may be added following similar flows.

In detail, the Smart Serious Game generates a list of the weather and traffic conditions for each day and time a student is late for, or absent from, a lecture or practical session. Continuing, the Smart Serious Game detects which condition re-occurred most commonly and presents it to the student in game. For example, where a said student is absent for *x* number of classes in a week, the game will uncover the most common condition, such as Heavy Rain, and inform the participant. The information changes on a weekly basis. By presenting this type of information to the student, it is possible they will uncover patterns regarding their behaviour, which they may choose to change. A host of alternative environmental data exists, such as public transportation, air quality and others. This thesis recommends utilising as much API data in Smart Serious Games as possible, to enrich the experience and the information provided to the audience, where possible.

This thesis includes traffic and weather APIs due to their open access. For the purpose of framework validation, it is pivotal that extrinsic networks integrate to the system and provide useful information to the student, however constraints such as the financial budget for research and development time needed to be addressed. Though the inclusion of other sources of data could provide new correlations and insights, it would not aid in validating the proposed framework any more.

6.3 SEA: Student Engagement Application

Student Engagement Application (SEA) is the name for the Smart Serious Game that overlays conventional student engagement measures using the physical environment to measure attendance and punctuality as a measure of student engagement through a hybrid wireless sensor network, and the software solutions discussed in the previous section.

This thesis labels SEA as a Smart Serious Game due to these key factors:

1) Data from the real world (traffic, weather) directly feed into the game and are presented to the end user.
2) Heterogeneous devices are intercommunicating for the purpose of the game.
3) The game utilises data sourced from direct sensor networks to affect gameplay.

6.3.1 User Interface

The user interface of SEA promotes a fun art style, with a minimalistic and logical menu that provides multiple methods of accessing key elements of the game not present in the main screen. This thesis focuses on a fun interface for the Smart Serious Game based on the findings of Deterding et al. (2011), who investigated the definition of gamification. In their publication, they uncovered a necessity for game user interfaces to be enjoyable, fun, and 'playful'. S. McCallum (2012) conducted a research project in Serious Games for personalised health and developed a user interface using the agile development methodology, directly feeding in user feedback into the design stage.

Moreno-Ger et al. (2012) investigated the development of user interfaces for Serious Games through usability testing. Their research, though focused on educational Serious Games, defined an instrument that sources feedback from users and provides a score in accordance with the effectiveness of the user interface. This thesis will not follow such a path as it runs the danger of the cumbersome use of questionnaires, which could interfere with the measure of student engagement at the experiment stage. However, this thesis will source data from participants, post experimentation, to validate the effectiveness of the user interface, and most importantly, identify if the user interface hindered user interaction with the Smart Serious Game.

Figure 6.4 SEA Menu System

The positioning of the menu system, displayed in Figure 6.4, reflects current games for mobile with a large audience and user engagement, such as the augmented reality game, Pokémon Go. The main menu button is situated centrally at the bottom of the screen, with the button alongside it reporting behavioural findings based on weather and traffic, sourced through extrinsic sensor networks. This provides access to key elements of the game and further options such as resetting the game cache. Users can access key elements such as the avatar gallery or the achievements section selecting the coin indicator, located centre-top of the screen, and the level indicator, located top left, respectively. SEA utilises multiple paths to the same game section to eliminate user strain when navigating the game.

6.3.2 Game Mechanics

SEA presents students with an avatar that reacts to the weekly measure of engagement. The main directive of the game is to maintain a happy avatar by obtaining a high score. In detail, there are five elements of progression in SEA: avatar happiness, avatar customisation, level mechanism, leaderboard, and achievements. Research by Doyle et al. (2010) discovered players engage better with a game or serious game when they are represented as an avatar rather than an image of themselves, supporting the inclusion of avatars in SEA. Avatar happiness is determined by the measure of engagement, produced by the data algorithm detailed in Section 5.5.2. If a student obtains an engagement value of forty, the avatar portrays an unhappy emotion, explaining that more engagement will make it happy, if the number is higher than forty but less than seventy-five, the avatar portrays a neutral emotion, explaining that it is happy but encouraging the student to achieve a higher score to improve its mood. If a student achieves a score higher than seventy-five, the avatar portrays joy, explaining to the student that it is feeling glorious. The simulation of engagement detailed in Section 5.5.1 justifies the scale of engagement measure to the level of happiness, where the points produced by the physical environment and self-reflection are considered.

High measures of student engagement allow students to unlock new looks for their avatars that they can apply in game. Each game point provides an extra coin to in-game currency for unlocking new avatar looks. SEA includes a set of six avatars that range from minor artistic changes to a full swap of the avatar.

Figure 6.5 displays the variance of avatar looks available to students. Students are provided with visual clues that indicate the availability of the look. If a look was unavailable, a padlock appeared with a red coloured price tag prompting the user that this look could not be purchased at this time. Available looks appeared with green price tags and no padlock. The use of consumable looks presents a form of inventory to students, allowing them to collect in-game objects.

The points required for each avatar look were determined by calculating the highest possible score a student could achieve during experiments, to ensure all looks could be unlocked. One thousand points are available for students to achieve during the first semester, accounting for the week away from campus due to Reading Week. All avatar customisations can be unlocked with eight-hundred points, providing the best-achieving students with a margin of two hundred points. Due to the flow theory (Csikszentmihalyi 1991), it is important the in-game objectives are challenging but achievable, to prevent students from disengaging from the game.

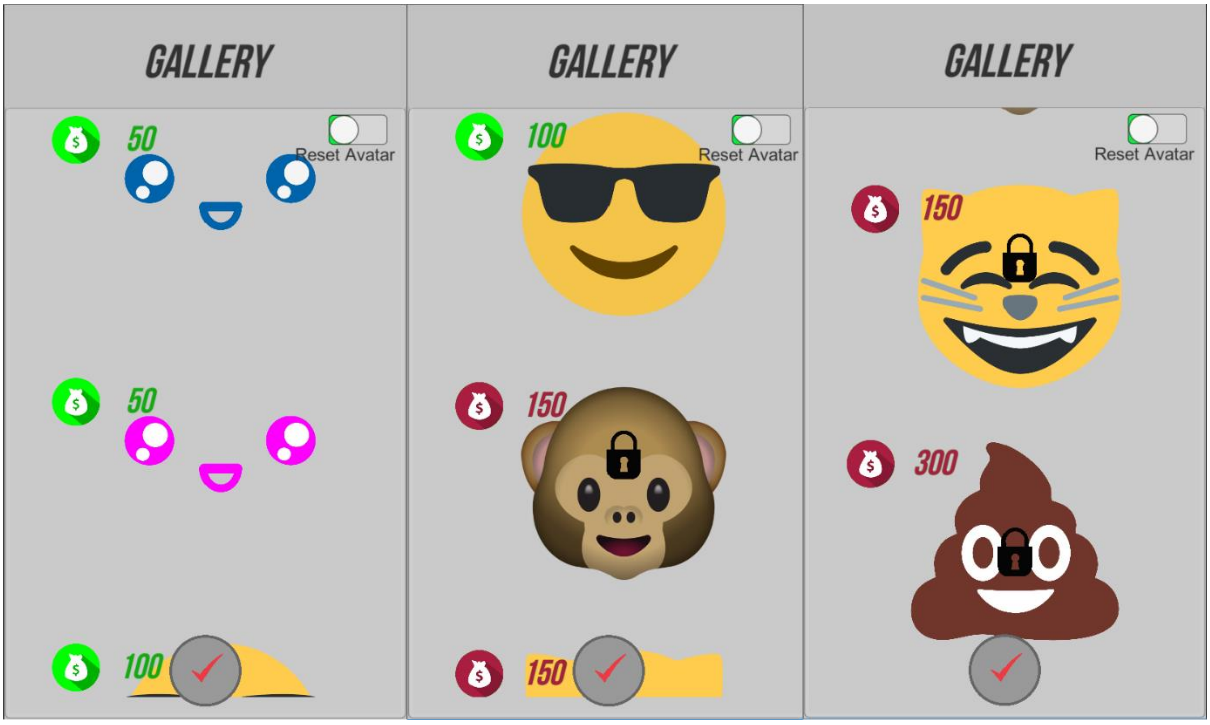


Figure 6.5 The selection of avatars available through the Avatar Gallery

SEA contains a set of three sprites for each avatar to reflect the emotion of an avatar in accordance with the student's measure of engagement. Figure 6.6 illustrates two examples beneath the gallery. The leaderboard displays the active avatar of the student, allowing them to display their avatars to all partaking students. Including the sprites allowed students to portray the measure of engagement as an emotion through avatars, providing more significance to the measure through the power of games and game immersion.

Figure 6.6 Examples of emotional variation per avatar.

Alongside avatars, SEA provides a level mechanism that rewards students on high measures of engagement. The level mechanism is only visible to the student and provides feedback and a sense of progression in the game. To level up, students needed to reach a points threshold that increased for every five levels of increase. This allowed students to level up faster, in the beginning, to draw them into the game further but became more challenging as the game progressed. In detail, for levels one to three, students needed to achieve fifty points to progress through the levels, level three to seven required one hundred, and level seven and above required two hundred. No consideration was given to levels above ten, due to the timeframe of three months as mathematically students can achieve one thousand points, equating to level ten.

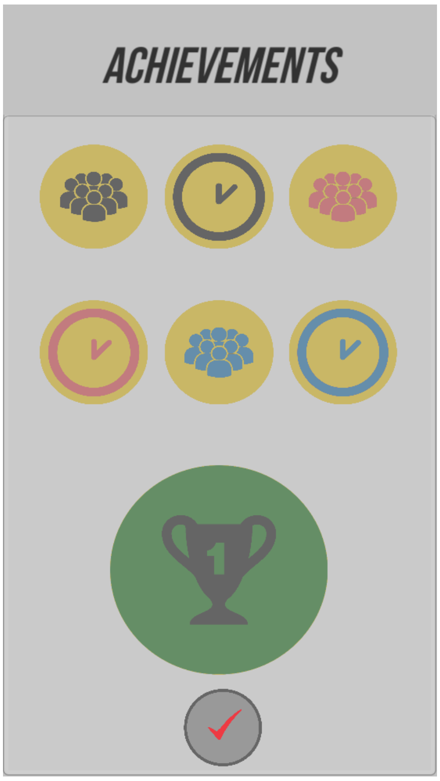


Figure 6.7 In-game achievements for students

In addition, SEA includes a global leaderboard to add an element of competitiveness that is accessible in-game but hosted in a webpage. Students climb the leaderboard by performing well in the weekly measures of engagement. As the measure is a percentage, students can achieve a maximum of one hundred points a week towards the leaderboard. Weekly engagement scores are summed through the weeks of experiments, rewarding consistency in engagement. Furthermore, SEA rewards consistency through in-game achievements, presented in Figure 6.7. Research by Hanus and Fox (2015) into gamification for improving student engagement outlined the use of achievements and a leaderboard as commonly utilised game mechanics in gamification for education, justifying the inclusion of these game mechanics in SEA. SEA rewards students for perfect weekly attendance, perfect weekly punctuality, perfect semester attendance, perfect semester punctuality, and placing first in the leaderboard. The discussed game mechanics and reward systems engage students with SEA, allowing for an accurate measure of engagement, achieved through gameplay.

6.3.3 System Development

SEA was developed in Unity3D, a game engine with a large online support network that allows developers to easily port games into different devices, such as Android, iOS and others. Unity3D supports JavaScript or C# for development.

The main concept of SEA is measuring student engagement on a weekly interval through intrinsic sensor networks and informing students of behavioural patterns with real-world events such as weather and traffic through extrinsic sensor networks. To achieve this, an event-driven system drives all virtual and physical student interactions with the game. In detail, on launch SEA determines the academic week number of the semester, in accordance with the university timetable, and retrieves the student’s calendar for the week. The system then proceeds to determine if the score for the previous week has been calculated and saved to the database and the day of the week, as different days will trigger different events. For example, if the student launches SEA on a Tuesday, and the previous week’s engagement score has been saved to the database, the game will load in the necessary values to portray the student’s updated progress. If the previous week’s engagement score has not been saved to the database, the system will begin to obtain the data stored from the intrinsic network for the appropriate week and compare it against the student’s timetable to generate game points for attendance and punctuality. Continuing, the system will obtain the score of the questionnaire and calculate the engagement percentage and save it to the database. Figure 6.8 presents the activity diagram of SEA to explain the programming sequence.

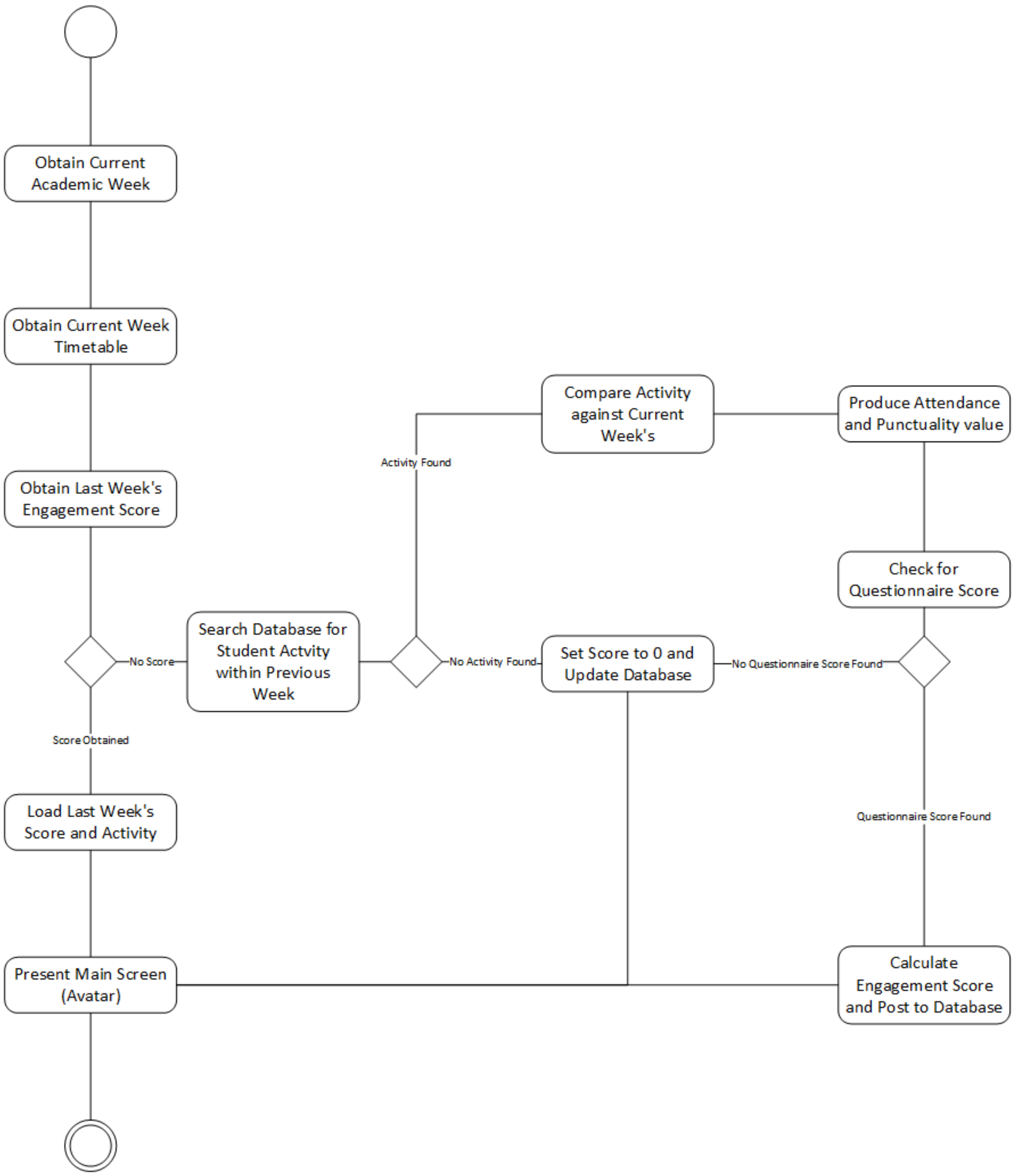


Figure 6.8 Activity Diagram of the key programming sequence in SEA

The above activity diagram only focuses on the key programming sequence of calculating student engagement at the launch of SEA, and therefore only presents a snippet of the programming required for SEA. Game mechanics such as the avatar gallery and achievements require their own programming sequence. Furthermore, Figure 6.8 does not include the programming sequence for obtaining the weather and traffic on the days a student is absent or not punctual, then posting this information to a database for data correlation.

The key message from this section of the thesis is underlining the programming structure of a Smart Serious Game that is based on events in the physical world for progression in-game. To achieve this, the Smart Serious Game must source data appropriate to the event it focuses on within the appropriate timeline. This thesis allocates data interpretation and validation from the Internet of Things to middleware rather than the game itself.

6.3.4 Game Architecture

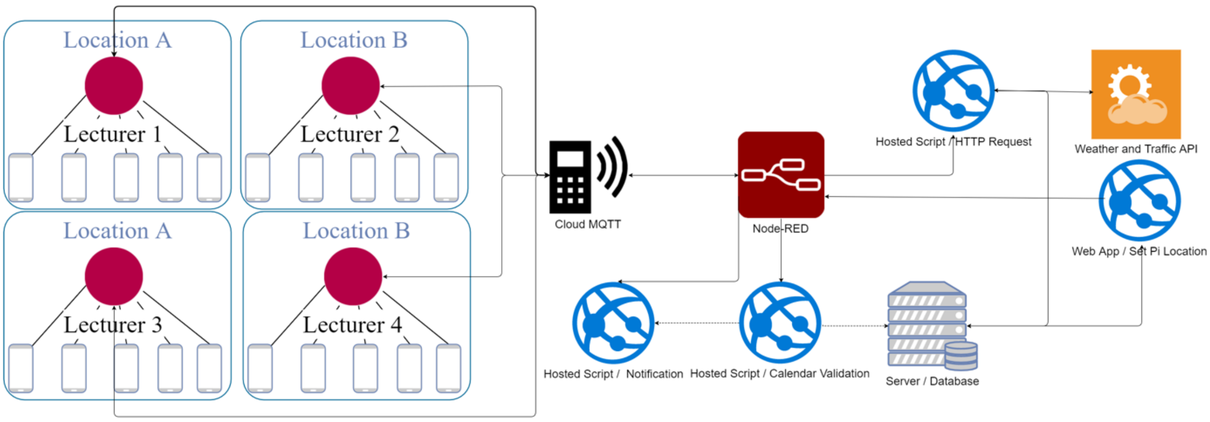


Figure 6.9 System architecture of SEA

Developing a Smart Serious Game generates technical challenges for merging physical and virtual network infrastructure relevant to the data requirements of an event-driven Serious Game. Figure 6.9 displays the system architecture of SEA, considering the physical placement of the intrinsic wireless sensor network, along with the system requirements for extrinsic networks, calendar integration, and user notification. In detail, for SEA to operate at the Liverpool John Moores University campus it must consider buildings as location variances as opposed to rooms within the buildings, as lectures and labs are held across two buildings for the Department of Computing. Furthermore, considering each room that a lecture or practical session took place in, would exponentially increase the edges of the network, meaning hundreds of Raspberry Pi would have been required to complete such coverage. To solve this, SEA utilises the Pi as a mobile node. Each lecturer involved in experiments will receive a Pi that travels with them to the lectures and practical sessions they monitor attendance in. Figure 6.9 presents a scalable system architecture; therefore, it could accommodate for static nodes, however, this is not necessary for the scope of this research.

With SEA's system architecture, the lecturer is provided with a web portal for setting the location of a Pi, as Section 6.2.1 discusses. This process is bidirectional, as once the location is set successfully; the appropriate lecturer will receive a confirmation email. The system architecture details the choice of two locations (A, B) and four Pi. Other network nodes can be utilised with the same result. This thesis opts for the Raspberry Pi 3 as it offers onboard Wi-Fi and Bluetooth, decreasing the scope of system development.

Sections 6.2.1 and 6.3.2 detail the process of registering student presence in conformity with their timetable. The presented system architecture displays this process by specifying the technologies and scripts required to complete the activity. In addition to the previous sections, the system architecture illustrates the process of informing students of their presence being registered through notification. Once the appropriate data is recorded in a database, a second hosted script triggers a notification, through the Batch API[8], to the student’s phone. Batch, thankfully decided to support this thesis for this feature. Finally, the system architecture illustrates the inclusion of traffic and weather data, as detailed in Section 6.2.3.

[8] www.batch.com Accessed 15/02/2018

6.4 Academic Portal

Section 6.2.1 discusses a lecturer's ability to update a remote node's building location through the Location Alteration System located on the nodes, however, lecturers require an interface to generate the message payload that instantiates the data process. To fulfil this need, this thesis developed a single interface web portal, excluding the interfaces for user login and sign up. Figure 6.10 illustrates the interface of the academic portal.

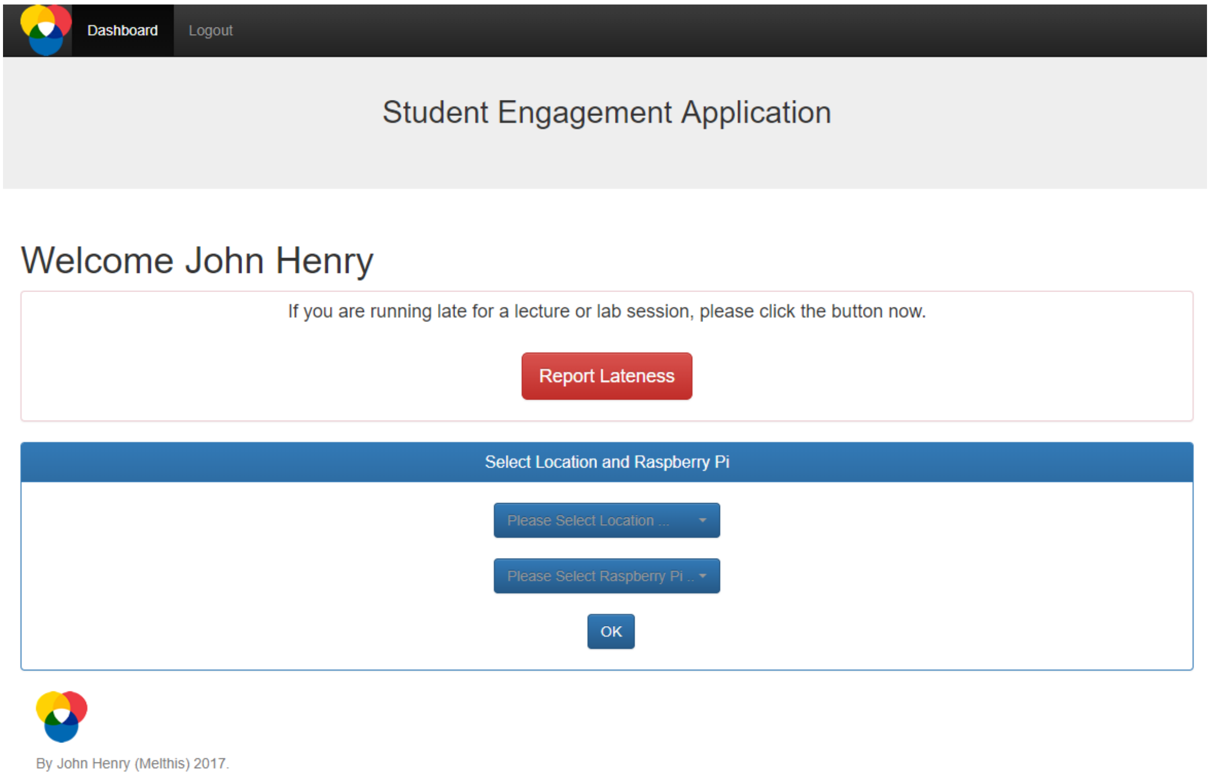


Figure 6.10 Academic portal interface

The simple and clean interface displayed in Figure 6.10 was achieved through the Bootstrap framework, allowing for minimum development. The interface consists of two, differently coloured sections; the red one at the top allows lecturers to report if they are running late for a session, and the bottom blue section instantiates the location change for the remote nodes. Research into Human-Computer Interaction, specifically for web design, promotes simple and clear interfaces, that allow users to identify what they need quickly (Neilsan 2001) and requires interfaces to be effective in user goal accuracy, efficient with minimal resources and satisfactory with user comfort (Dix et al. 2004), supporting the design of the portal. It is pivotal that the portal is user-friendly, as a cumbersome interface would cause erroneous data at the attendance registration stage, resulting in system anomalies.

The academic portal consists of two programming requirements, the ability to change a remote node's location and the ability to report lateness to a session at a specific date and time. Handling the latter is POST request in PHP that inserts a new record in a table with the current date and time. For changing the location of a remote node, this thesis developed a request using MQTT that communicates the parameters of the dropdowns pictured in Figure 6.10. Continuing, the data process followed the activity described in Section 6.2.2 and illustrated in Figure 6.2.

Emails were used in the academic portal to confirm a change in the location of a remote node, as Section 6.2.2 details. This thesis utilises emails instead of a notification embedded in the academic portal for simplifying the development. This research presumes lecturers monitor their emails frequently, therefore posing no issue in utilising the service as a means of effective communication.

6.5 Electronic Questionnaire Portal

The final element of the developed solution for this thesis is the Electronic Questionnaire Portal. This portal houses the electronic copy of the questionnaire administered to students playing SEA and is responsible for gathering the responses of students that partake in the experiment, but do not play the game, forming control groups.

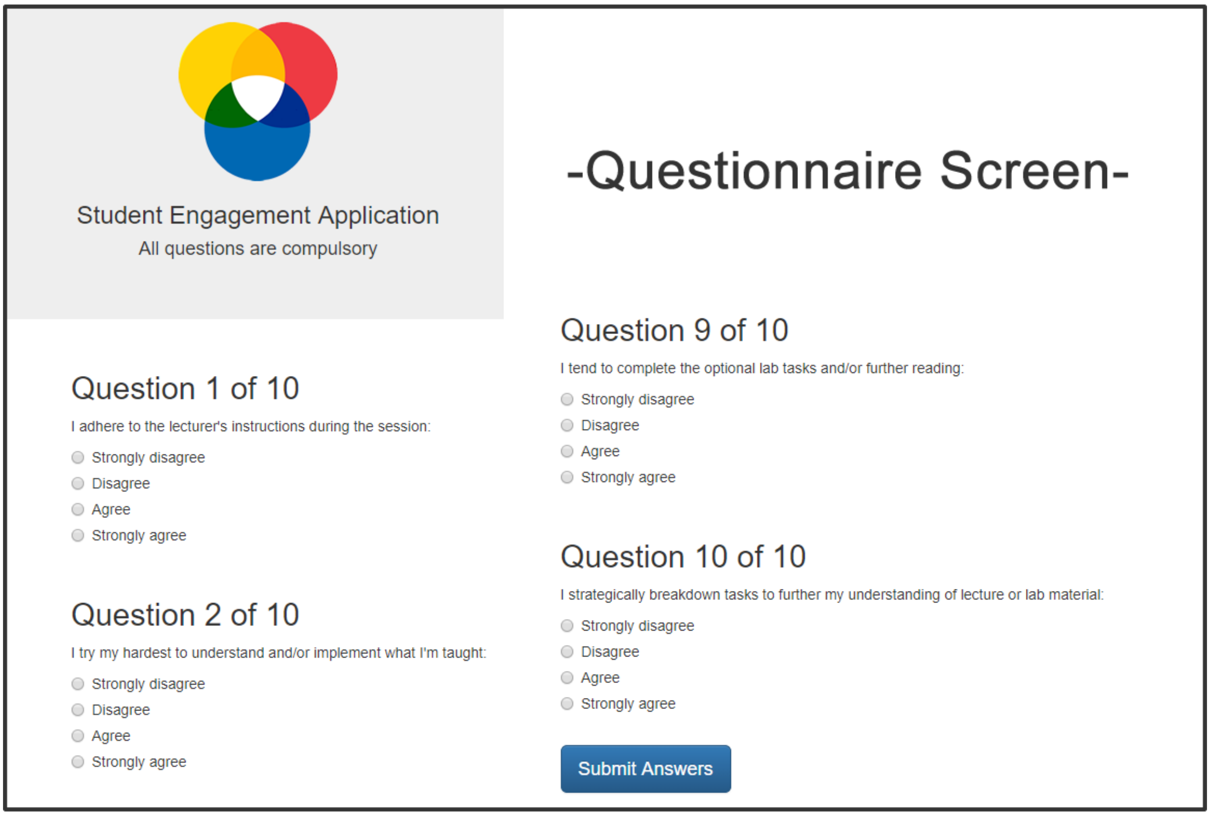


Figure 6.11 Electronic Questionnaire Portal

The interface of the Electronic Questionnaire Portal conforms to the web design requirements of human-computer interaction specified in the previous section. A single panel greets the partaking students, and if a questionnaire is outstanding when they visit, they are navigated to the questionnaire screen with a click of a button. The questionnaire is identical to the one found in SEA, and follows the common theme for online questionnaires, allowing students to feel comfortable when using it (Dix et al. 2004).

Once students complete the questionnaire, it is stored in the database for the purpose of data analysis. If a student visits the portal having completed their weekly questionnaire, they are prompted with a message in the panel, which replaces the content displayed in Figure 6.11, stating that the current weekly questionnaire is complete, and the date and time when it was completed.

By utilising a web portal for collecting electronic responses to the self-reflection questionnaire, informing students of outstanding questionnaires became a challenge. Student emails and an email system was produced to reduce development complexity and alert students in intervals if required. In detail, using Node-RED, a timed script executes three times a week, on Monday, Wednesday, and Friday. If a student has not completed their weekly questionnaire, the system emails the respective student, with a message reminding them of the outstanding questionnaire and a link to the portal. The following chapter discusses further interventions for both control groups if the student response rate dropped significantly.

6.6 Portal Data Activity Processes

Section 6.4 and 6.5 discuss the two web portals developed as part of this thesis and detail the utilised technologies and designs. Expanding on the previous sections, this thesis provides a walkthrough of the data sequences for each portal, focusing on how academics and students register with the portal, and how they generate data, respectively.

6.6.1 Portal registration

The experiment procedure requires academics to register with a bespoke portal that controls the location of the remote, autonomous node that monitors student attendance in lectures and labs. Furthermore, academics can inform of their lateness through the portal, allowing the researcher to assure the appropriate engagement scores were provided to students. Students must register with a portal that sources questionnaire responses weekly and produce email prompts if a questionnaire has not been completed. Figure 6.12 illustrates the data process relative to portal registration for academics and students.

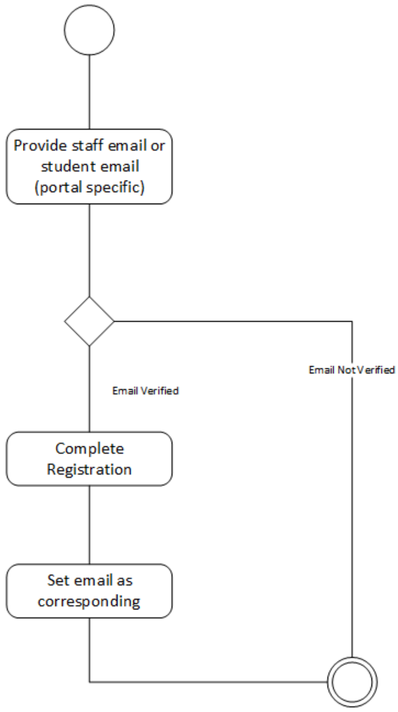


Figure 6.12 Activity Diagram illustrating the data process relative to registration with a web portal.

An academic provides an email that associates with their university role, where a student can provide any email. Academic emails are verified by ensuring the domain matches the one set by the university. If it does, the academic is informed that an email has been sent requesting them to confirm the provided address, otherwise, an error states that the academic entered an incorrect email. This validation does not exist for students. After completing the electronic form, an email is sent asking the respective user to confirm their email address. Once the email is confirmed, the web applications will utilise it to notify users when required.

6.6.2 Data acquisition

As previously discussed, the data acquired from each web portal varies greatly, therefore it would be impossible to explain the data process in one figure. The academic portal sources two data, only one of which it stores. The main data stream will be the communication between the web application and the cloud broker, allowing lectures to alter their node's location. Secondly, they can notify the researcher of a session they have started late. Figure 6.13 illustrates the data processes.

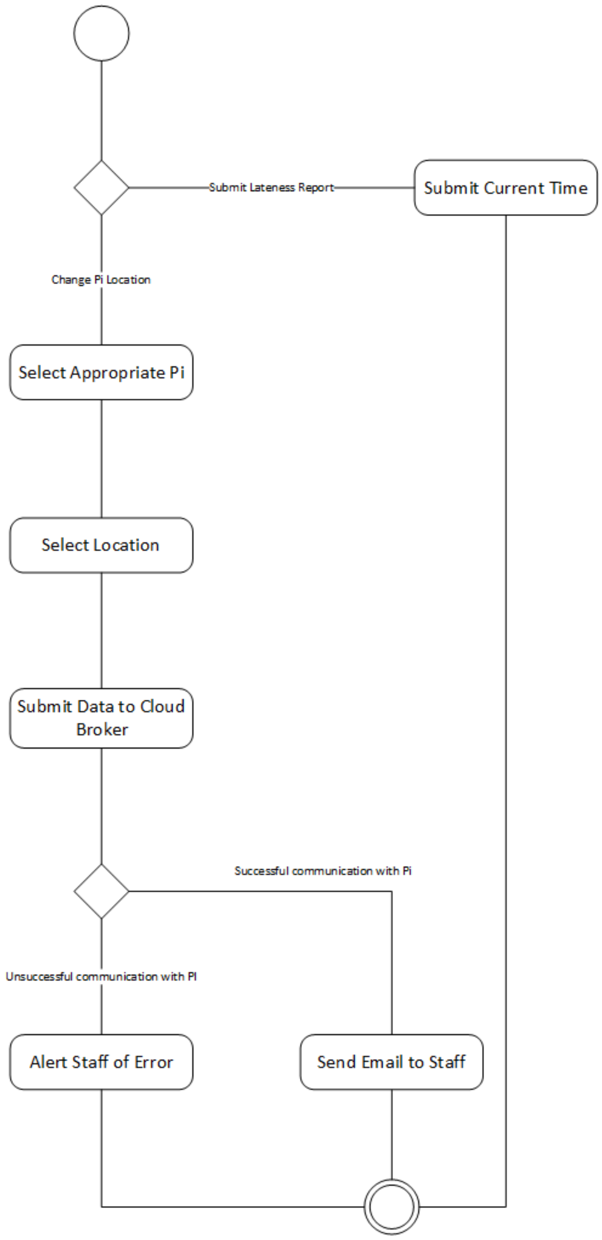


Figure 6.13 Activity diagram for academic portal data processes.

Each process instantiates through user input. If the academic chooses to inform the researcher of a late class, the web application stores the current date and time into the database for further analysis, concluding this data process. If the academic chooses to change the location of their node, they must select the node they have been associated with by the researcher, select the location at which they wish to change the node to and submit the data to the cloud broker. If the message does not reach the broker, then academics are alerted within the portal.

Otherwise, if the node does successfully change location, the academic receives an email originating from the node itself, concluding this data process.

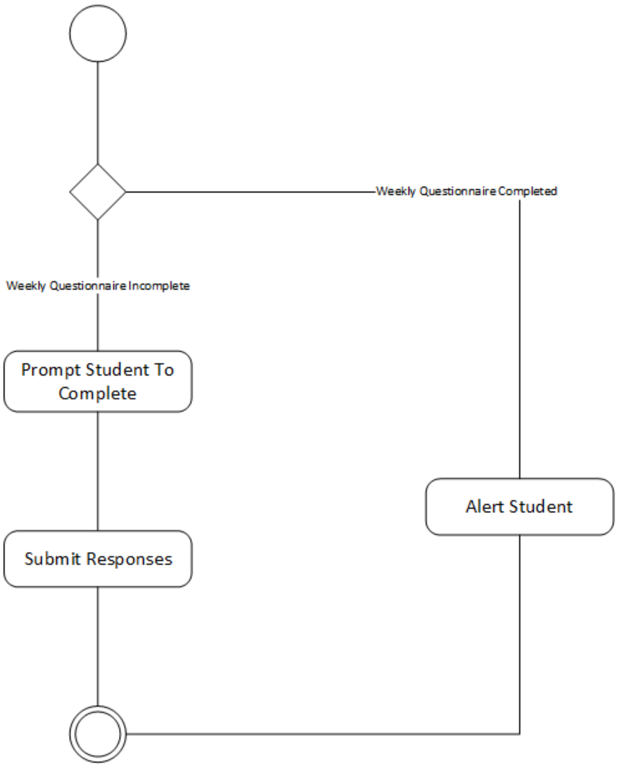


Figure 6.14 Activity diagram for the student portal data process

Figure 6.14 displays the data process for acquiring questionnaire responses from students through the student portal. When a student visits the portal, the main area will either display a prompt informing the student to complete their questionnaire, with a link directing them to the questionnaire or will inform students that this week's questionnaire has been completed, concluding the data process. Alternatively, the data process concludes when the weekly response has been received. Section 6.5 discusses the email alerts aimed at reminding students of incomplete questionnaires during set intervals through a week. This feature does not interact with users and therefore is not included in this section.

6.7 Chapter Summary

This chapter presents the process for developing a Smart Serious Game along with the accompanying systems required to operate in the physical environment and form control groups for experimentation. In the beginning, the chapter focuses on the development off the integration of intrinsic sensor networks with a Smart Serious Game, detailing the programming elements of the remote nodes, middleware, and the programming requirements for the extrinsic networks. Furthermore, this chapter details the development of SEA, the Smart Serious Game that measures student engagement, and justifies the choices made during the development process by presenting relevant literature. Finally, this chapter explains the development of the two web portals that accompany the delivered software solution of this thesis. The following chapter presents the experiments conducted to evaluate the proposed framework and developed systems.

CHAPTER 7 – SYSTEM EVALUATION AND DISCUSSION

7.1 Introduction

This chapter details the undertaken three-month experiments that validate the proposed modular framework for combining Serious Games with the Internet of Things. Students in undergraduate degrees at Liverpool John Moores University were recruited as participants. A prolonged observation provided a large amount of data, which will help determine the effectiveness of the data algorithm and the proposed modular framework, used to develop the prototype.

Furthermore, this chapter evaluates if the developed Smart Serious Game (SEA) can accurately measure student engagement and compares the measures from control and treatment groups through data correlation and data triangulation. Data correlation examined the measurements of engagement from both groups, against the academic performance of the students involved. Handlesman et al. (2005) state that academic performance is as an outcome of student engagement, therefore this thesis theorises the adverse process as a means of validating student engagement measurements. In addition, this chapter presents the survey used to collect the qualitative views of students on the experiment experience and analyse them against their quantitative measures.

Additionally, this chapter presents findings surrounding participant response rates from self-reflection instruments and provides an insight into student behaviour and weather patterns, in relation to attendance.

7.2 Experiment Design

This thesis undertook experiments, post participant recruitment, that aim to prove the validity of our proposed framework, by utilising control and treatment groups. The first stage of the experiment process allocated participants to a group at random. Then, participants provided their student numbers, so the appropriate gatekeeper could identify the respective student grades for data analysis. This project secured physical documentation and computer data at all times to prevent data leaks and preserve data integrity.

The control group (Group A) gathered a measure of student engagement using self-reflection tools, as practised in current academic studies. The questionnaire required weekly completion. Students that failed to complete the questionnaire received no mark for the week. The treatment group (Group B), measured student engagement through a Smart Serious Game named SEA (Student Engagement Application) that embeds self-reflection tools within the game. SEA accounts for attendance and punctuality values obtained from a purpose-built wireless sensor network, consisting of Raspberry Pi. SEA also requires input from respective lecturers to maintain the location of their autonomous node. Group B was also required to complete a questionnaire weekly.

Group A was required to fill out a questionnaire on the last day of the week. Participants were prompted by email to ensure most questionnaires were filled. No other data, but the Student ID, reflective scores, and student email were sourced from Group A.

All of the following statements only applied to Group B. By utilising the Internet of Things, no intervention was required from the researcher while the experiments ran for participants recruited in Group B. Participants automatically checked-in to classes based on their phone’s location and degree programme’s timetable. For a check-in to occur players left their

Bluetooth active. The system actively sought for Bluetooth addresses that belonged to participants, as these were obtained by participants manually entering them into the system.

Environmental data regarding weather and traffic were also sourced automatically based on a degree programme’s timetable, for example, a class that starts at 9 am would trigger a call for the related traffic data to be obtained for the route between their term-time address and the building in which the class is taking place. Participants only entered their postcode for their address and never the home or flat number. This was to limit the possibility of participant identification. The only time-consuming element for participants was when checking their scores and playing the serious game (available on iOS and Android smartphones). Participants were also asked to provide their travel mode, such as driving, when signing up. If they did not travel in by car they would not be required to provide their postcode.

The serious game is event-driven. This means in order to progress and achieve a score, participants needed to attend their classes in a punctual manner. A standard questionnaire needed to be completed at the end of each academic week. The questionnaire obtained all other aspects of engagement that the Internet of Things alone failed to in this Smart Serious Game (behavioural, cognitive, and emotional student engagement). At the end of each academic week, participants were prompted by the game to complete a questionnaire after 5 pm on a Friday. This questionnaire was available for the participant to complete up until Monday. The questionnaires were completed at their own leisure and therefore presented no distraction from their studies. The game provided feedback on the activity of the student through graphical representation and mobile phone notifications.

Consent was obtained before any participant began playing the game, and an information sheet was provided detailing the experiment design. Participants were not obliged to commit to this study. Participants were allowed to withdraw from the study at any time. It was possible to erase any data obtained by participants if they chose to leave early.

If participants chose to withdraw they were asked to notify the researcher as soon as possible. This allowed their Bluetooth Address to be deleted from the system to stop all tracking activity. Furthermore, participants needed to delete the application from their phone and delete the respective application certificate. Instructions on how to do this were sent to participants via email. (Group B). All participants received a confirmation email when all of their data had been deleted and they had been removed from the system.

The first time a participant ran through the game a tutorial mode appeared explaining how to play the game. The researcher's contact information was provided in-game to assist participants.

During the semester and based on their attendance, punctuality, and questionnaire scores, an engagement score was produced. This score represented the aggregate weekly amount of engagement per attended lecture or lab and allowed the game to progress. Each point gained through positive engagement correlated to a unit of in-game currency. Currency allowed players to purchase a variety of colours and virtual faces to customise their avatar. To provide a more comprehensive measure of student engagement, the game prompted players to complete a questionnaire per week. This is the most that a participant was asked to do. Questionnaires did not have to be completed directly after a lecture or lab but needed to be completed the same week. Questionnaires are a vital measure of student engagement with a lecture or lab. It is the aggregate score of what participants do (attendance and punctuality values) and how they feel regarding a lecture or lab (questionnaires) that constructs the final engagement score available to participants.

It is important to highlight that no one but the lead researcher had access to a student's reflective views. Scores were provided by answering a question scaled from 1 to 4 (where 4 is most). For this study, it was not necessary to correlate the subjective views of Group B with their game scores, as the game score provided all the information needed. In relation to Group A, participants were identified through this experiment. This was vital to monitor the measure of engagement.

To validate the results of both groups (A&B), partaking students' academic performance (grades) and retention, in their programme, were analysed against each other. Further information on data analysis is included in Section 7.5. All data regarding programme retention and academic performance were identified by the appropriate gatekeeper and anonymised to prevent participant identification. To make this possible the Student ID of all participants were sourced electronically and stored securely in a database, protected by Liverpool John Moores University's security measures. The gatekeeper was the lecturer of each module related to the program that the participant was enrolled on. As mentioned above, there was no disadvantage to the lecturer being able to indirectly or directly identify students that were participants, as they did not have access to the game data, performance or subjective views. This analysis provided a strong indication towards proving the case study and the effectiveness of the framework. At the end of the semester, participants were required to fill out a questionnaire that sourced their views of their experience during the project. These views will aid in validating the use of the Internet of Things in Serious Games by using data triangulation against the obtained measures of student engagement.

It was not possible to identify students by correlating their module mark and attendance. This is because the module marks were anonymised, and there could be no guarantee that the scores achieved in the game would correlate with their module mark. This study did not investigate the effect of playing the game and the module mark, however, it did consider the module mark as the output of engagement.

7.3 Participants

In the process of recruiting participants, undergraduate and postgraduate students based in the Faculty of Engineering and Technology at Liverpool John Moores University were approached through an invitational email.

Specifically, students from the Department of Computer Science formed the audience of this project. This demographic of students was targeted due to the relevance in the domain, hypothesising that students would show greater interest in becoming a participant. And the established rapport with lecturers, meaning they were more likely to promote the project to their students and increase participant recruitment. Furthermore, programmes such as Computer Games Development and Computer Science within the Department have indicated poor retention rates. Obtaining information from this group could prove valuable for improving the retention rate in these degree programmes.

Emails only formed one method of recruitment. Programme leaders that were supportive of this thesis also promoted the research project to their students. Posters were placed where possible within the Faculty. Finally, the researcher presented this project at the end of lectures schedule permitting.

The recruitment campaign gathered twenty four participants, however, two participants withdrew after signing up, resulting in twenty-two participants that completed the experiment. It is possible participants were repelled by the length of the experiment and the weekly intervention. No data was sourced from students that did not partake in the experiment, in accordance with the university's ethics guidelines, with the ethical approval number of 17/CMS/003.

Existing research utilises similar sample sizes for control and treatment groups, such as investigating effects and experiences of Serious Games on undergraduate players (Chiang et al. 2008), investigating the use of simulation games for vocabulary learning (Miller & Hegelheimer 2006), and evaluating virtual worlds in regards to social behavioural elements (De Lucia et al. 2009). Based on these publications, this thesis can form conclusions with the number of recruited students.

Participants had a computing background and covered all three levels of undergraduate study. Both groups interact with a computer-based application, one developed for the Web and the other for smartphones, therefore no group nor participant gain any form of advantage or disadvantage based on their academic background.

In total, the experiment period sourced data from one hundred and forty-nine data points, out of a potential two hundred data points.

7.4 Experiment Setup

Post-recruitment, participants were randomly allocated to two groups, Group A and Group B, using spreadsheet software and the random number generator feature. As such this experiment is considered to have followed the principles of a Randomised Controlled Trial. The decision to use such an experiment setup was based on the findings of a literature survey into Serious Games that discovered a lack of Randomised Controlled Trials when investigating the positive effects of Serious Games (Connolly et al. 2010). Group A is the control group, where participants provided measures of student engagement through a self-reflection instrument. Group B is the treatment group, representing the new measure of student engagement, which utilises Smart Serious Games and a self-reflection instrument.

The questionnaire was developed based on the research stated in this thesis but adjusted to ensure that a positive response gave a higher score. To increase the possible response rate from questionnaires this thesis followed the recommendations detailed in a systematic review into electronic and postal questionnaires conducted by P. Edwards et al. (2009), and ensured the electronic questionnaire comprised of a white background, textual representation for responses and had a set deadline for completion. After ensuring that positive questionnaire responses produced a higher number, the sum was fed into the data algorithm for engagement mentioned above.

By obtaining the respective averages, this thesis compares the overall perspective of the data and attempts to validate the measure of engagement against academic performance. Previous literature (Handlesman et al. 2005) states that academic performance is the outcome of engagement, therefore this thesis utilises student performance to validate the measure of engagement from both groups.

Data analysis on the groups began with the calculation and comparison of the average engagement measure and grade per group. A greater similarity between the averages per group indicates a strong measure of engagement. Figure 7.3 presents the averages for the Group A (control group) and Figure 7.4 presents the averages for Group B.

Section 5.4 details the data algorithm used for measuring engagement in Group B, creating an engagement percentage, identical to the grading mechanism used in higher education, with a scale of 0 to 100. Group A measured engagement using conventional self-instruments. Their measure provided a total of 40 points per questionnaire, where ten questions included a response scale of 1 to 4. This produced an issue, as data from Group A needed to be interpolated to match the percentage of Group B to perform data analysis. To achieve this the research calculates the percentage of the self-instrument measure and divides by the total score, for instance, a total of 34 points divided by 40 points. Subsequently, to obtain the percentage multiply the sum (0.85) by 100.

7.5 Analysis and Findings

The key novelty of this thesis is the modular and interconnected framework for combining Serious Games and the Internet of Things. The evaluation process of the proposed framework involves the development of a Smart Serious Game that measures students' engagement with their academic programme. This thesis attempts to validate the framework by meeting the following criteria:

- The framework successfully develops a Smart Serious Game that utilises the data from the physical environment for gameplay.
- Data generated from the Smart Serious Game draws a conclusion on the measure of student engagement.

Before visiting the data findings from experiments, it is important to note the proposed framework did result in the production of a Smart Serious Game that utilises data from the physical environment to further gameplay. Students did interact in a pervasive manner with the implicit wireless sensor network comprised of Bluetooth remote nodes and smartphones. The network successfully obtained data when students attended their lectures and practical sessions on a weekly basis; however, two students reported issues with the Bluetooth system, producing data noise. This noise is analysed in the following section. Furthermore, middleware systematically obtained weather data and this thesis has successfully correlated weather conditions with user behaviour. The following section details the findings. No participant utilised a car as a means of transportation to the campus, therefore no traffic-related data was obtained.

The modular interconnection of the framework proved true, with the middleware section holding the responsibility for data interpretation, data manipulation and data validation. In reflection, a distinction must be made from the data processing module. Though data processing is a part of the middleware module, it does not define the development and deployment of these modules on Internet hosted areas or local servers. Data processing is performed on participant smartphones but does not belong in the application module. Every Smart Serious Game will require data of unknown velocity, and this data will require processing, resulting in the module disassociation from the application.

Summarising, the framework did result in the development of a Smart Serious Game that sources data from the physical environment to further gameplay, proving the effectiveness of the framework from a developmental perspective. The following sections assess whether the data obtained from the Smart Serious Game forms a conclusion, to validate the proposed framework.

7.5.1 Response Rate in Groups

This thesis overlays conventional self-reflection measures of student engagement with a data algorithm that sources values from a Smart Serious Game. Both stated experiment groups utilised self-reflection. Group A sourced all its value from self-reflection, emulating conventional measures of student engagement, whereas Group B utilised a hybrid measure of self-reflection and data algorithm generated score. Completing the self-reflection instrument was a core element of the student engagement measure for both groups.

Chapter 6 justifies the development choices made for creating the questionnaire, by presenting related human-computer interaction research in the domain, therefore the following data results do not stem from a design flaw. The previous section presents a large variance in the measure of student engagement on a per-student basis and their academic performance, between the groups. Investigating the completion rate of the self-reflection instrument in both groups justifies this variance.

Elaborating, Group A completed the self-reflection instrument on average of 49.25% throughout the experiment. Their completion rates resulted in a standard deviation of 23.75, highlighting a wide range of relative data points. Figure 7.1 illustrates the group's weekly completion percentage and the average engagement percentage. The data displays a trend where the smaller the completion percentage the higher the group engagement average. This trend derives from the responses of students during the weeks of low completion rates, where responses indicated a high level of engagement from the small cohort that responded. This trend cannot conclusively state that low participation from a group will result in inflated measures of engagement but does state the inaccuracy in the measure that a limited amount of participation produces.

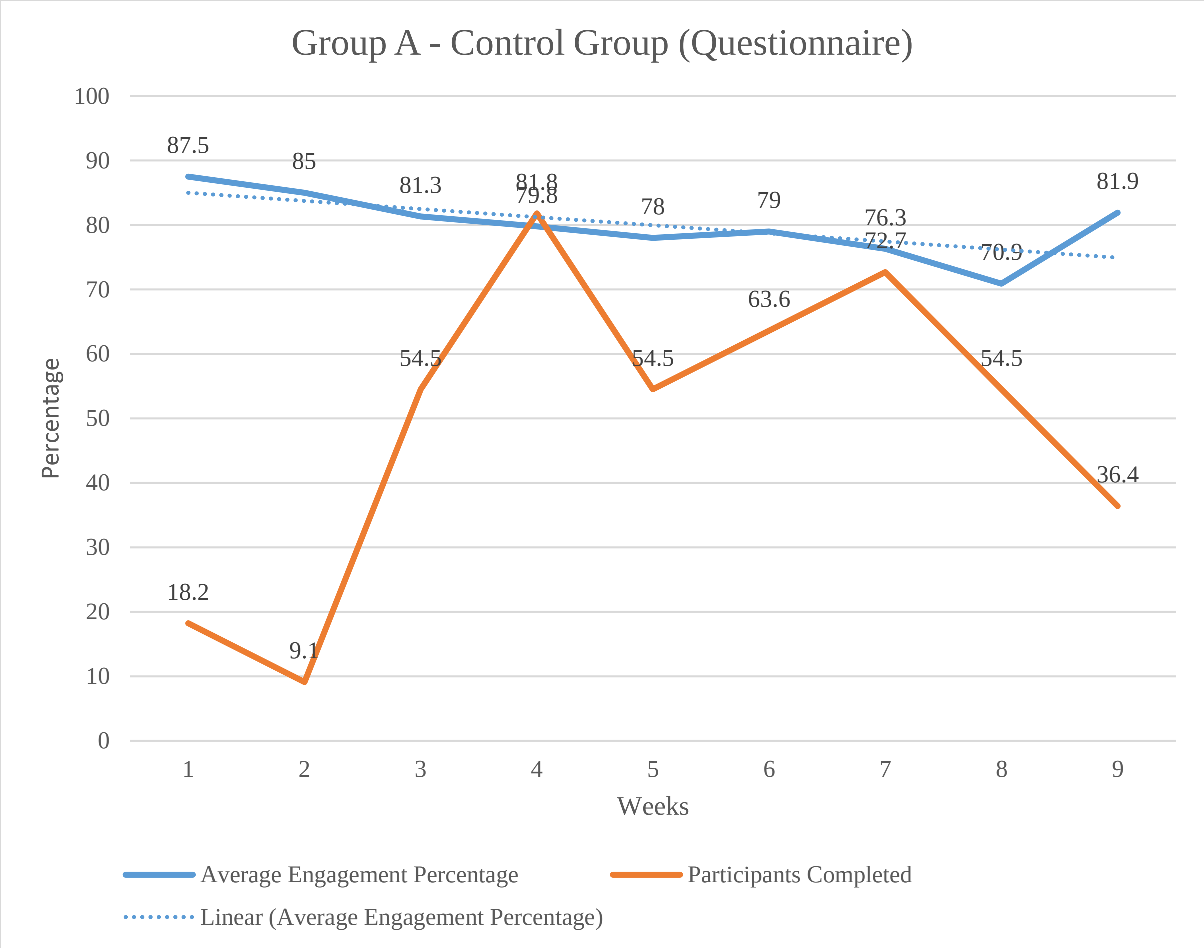


Figure 7.1 Group A (Control group): Weekly group average questionnaire completion and engagement

Group B completed the self- reflection instrument on average 80.05%, an increase of 30.8% over the control group (Group A), producing a standard deviation value of 21.84, a decrease of 1.91 in comparison to Group A. Figure 7.2 displays the related findings. The lower standard deviation value highlights a consistently better response rate over Group A, a fact that the increase in average confirms. This, in turn, validates the results presented in the previous section, which stated a better measure of student engagement for Group B on a per-student basis.

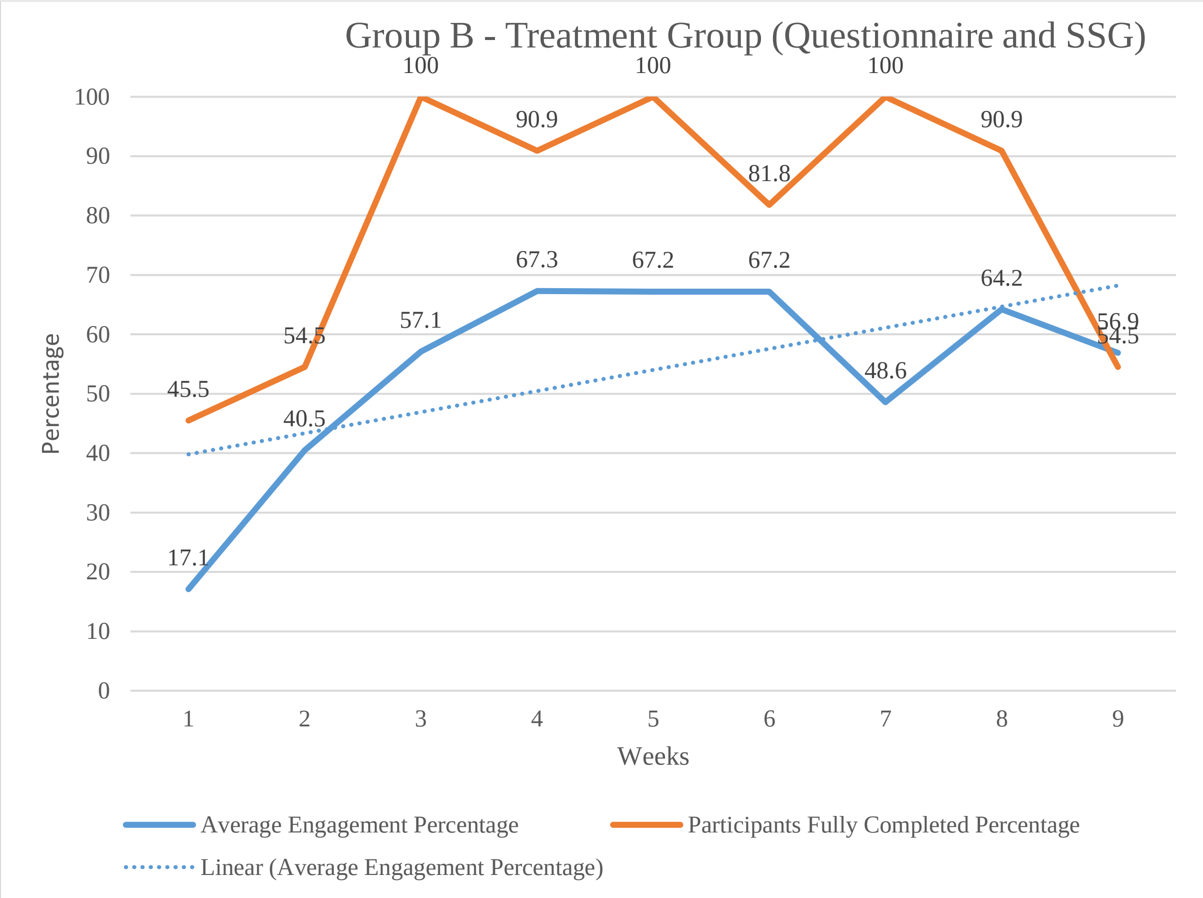


Figure 7.2 Group B (Treatment group): Weekly group average questionnaire completion and engagement

As mentioned above, both questionnaires were developed using best practices identified through background research. Furthermore, both groups could access the questionnaire through their mobile phones, resulting in identical accessibility. The stark difference between the participant experiences per group was the inclusion and exclusion of game immersion respectively. Game immersion is known to influence behaviour and performance in learning (Blohm & Leimeister 2013; Deterding et al. 2011; Garris et al. 2002). This data set suggests that game immersion positively affects completion rates with self-reflection instruments when embedded as a game mechanic. This finding can aid research across all domains that utilise questionnaires for obtaining data.

7.5.2 Group Data Comparison

On average, Group A (control group) produced a student engagement measure of 70.07 and an average grade value of 61.14, a difference value of 8.93. This perspective suggests that self-instrument methods for measuring student engagement produce valid readings, supporting the research presented in the literature review section of this thesis.

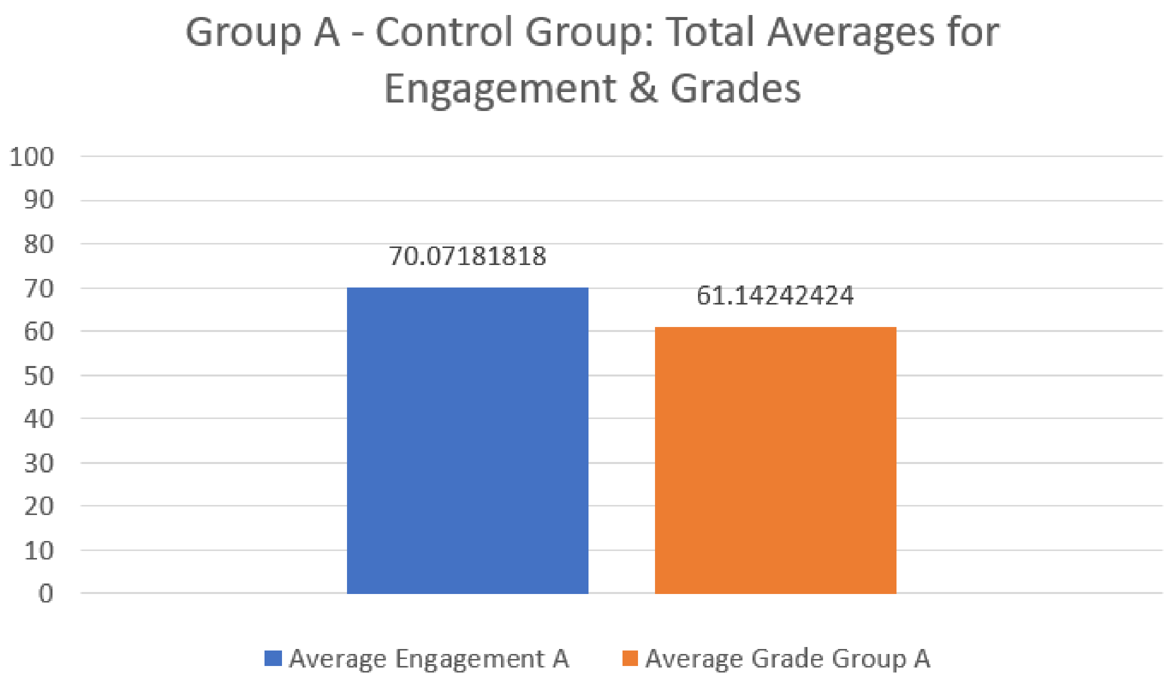


Figure 7.3 Group A Averages

Group B (treatment group) produced an average engagement value of 53.13 and an average grade of 63.72, resulting in a difference of 10.59. The difference in averages is higher in Group B in comparison to Group A, suggesting self-instrument to be a more accurate method for measuring student engagement. This perspective does not dismiss any correlation between the measure of engagement through the Smart Serious Game and academic performance, therefore the measure is valid.

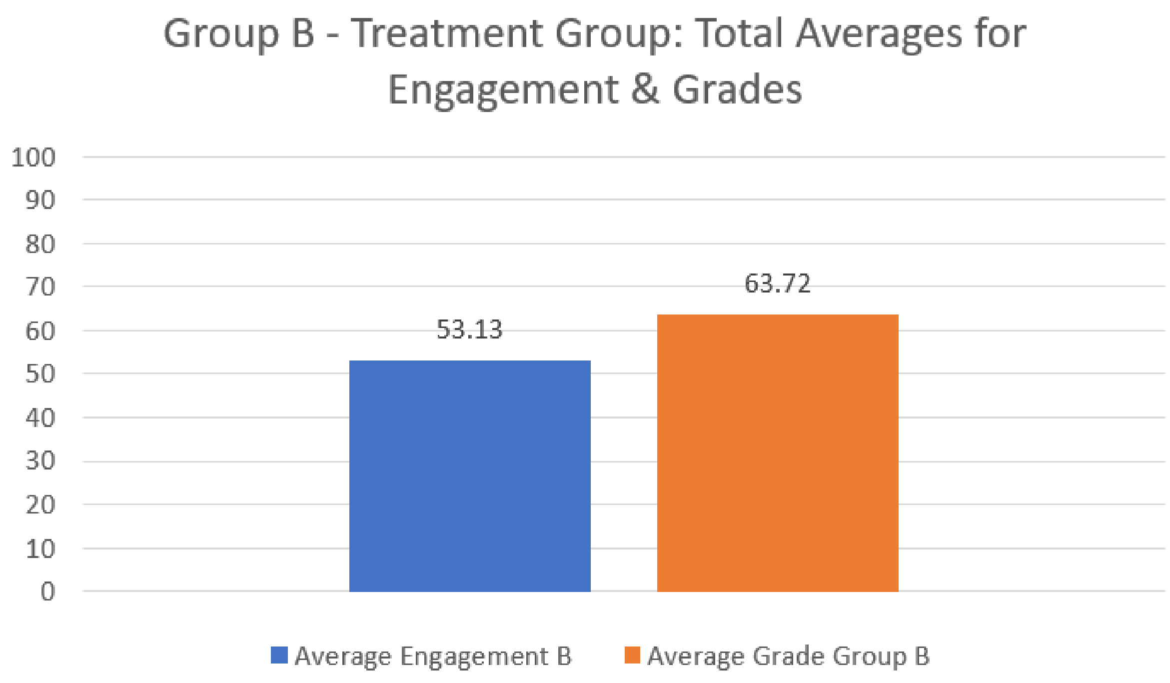


Figure 7.4 Group B Averages

To better comprehend the results from the data, this thesis delves into the dataset and examines the relationship between the average engagement value per student and their academic grade. This further analysis provides a clearer perspective on the similarity between student engagement and academic performance, whilst examining the data for any noise. Both groups utilised electronic methods for data capture. It is possible the developed technology hindered data acquisition, skewing results. Furthermore, students could experience extrinsic circumstances, such as dropout, which too would skew the results. The following section investigates these issues.

Figure 7.5 illustrates the relationship between student engagement and academic performance on a per-student basis for Group A. The orange line highlights engagement and the blue line the average grade. (If this thesis is read in black and white, it is the lighter shaded line that represents engagement.) This research utilises the correlation coefficient *R* to correlate between the student data points. The correlation coefficient R, also known as Pearson's *r* was presented in the 1880s (Stigler 1989) and is used to calculate the correlation between numerical arrays.

$$r = \frac{\sum_{i=1}^{n} \left(\frac{x_i - \bar{x}}{s_x}\right)\left(\frac{y_i - \bar{y}}{s_y}\right)}{n-1} \qquad (7.1)$$

Equation 7.1 displays the stated calculation. In detail, the statistical algorithm produces the sum of two variables, formed by calculating the tendency of variance, divided by the degrees of freedom (Boslaugh & Watters 2008). The nature of this statistical algorithm allows this thesis to investigate the correlation between the array of grades and array of engagement scores, in an attempt to validate the acquired measures of engagement.

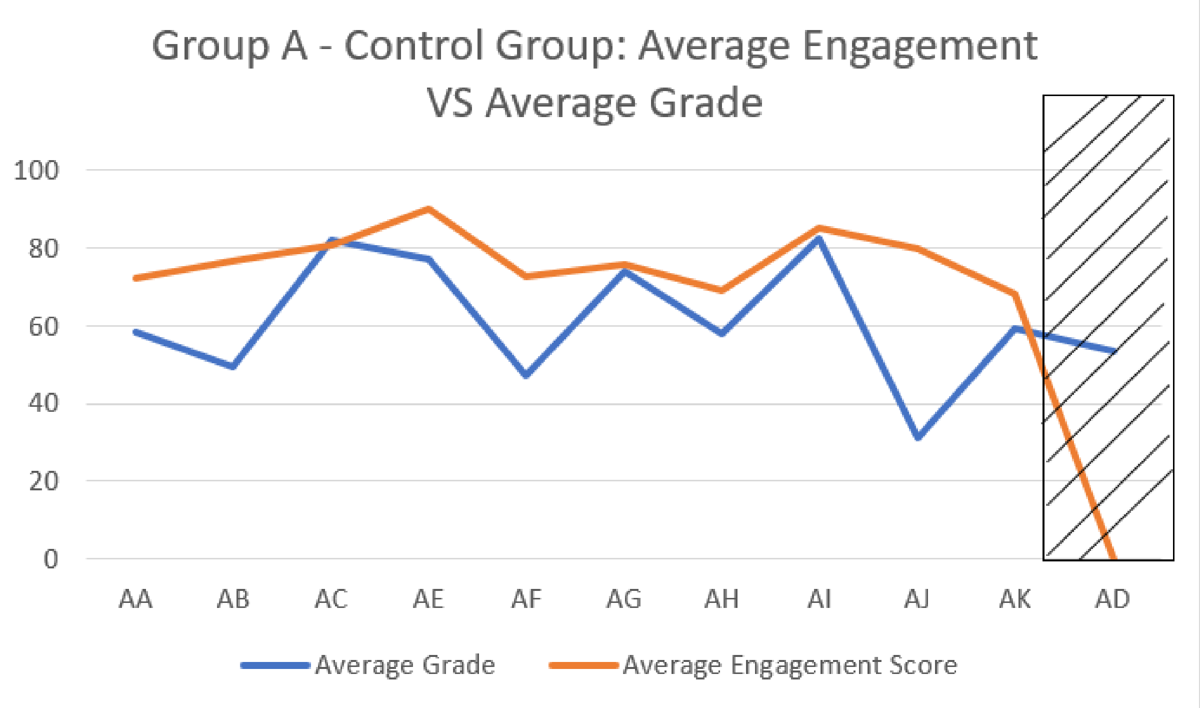


Figure 7.5 Group A Average Engagement and Grade per student

Initially, the data from Group A produced a correlation coefficient *R*-value of 0.27, indicating a slight upward correlation. Statistically, a value of 0.27 would not indicate a correlation between the measure of engagement from self-reflection and academic grades. Further investigation highlighted a single student, code-named AD to protect anonymity, had approached the respective programme leader of the course expressing his desire to withdraw from the university. This explained his lack of involvement with the experiment and in turn, his poor measure of engagement. As no data points were captured from the participant, the academic grade was classified as noise. Recalculating, the *R*-value emitting data noise increased to 0.44. This result presents a weak upward correlation for the group.

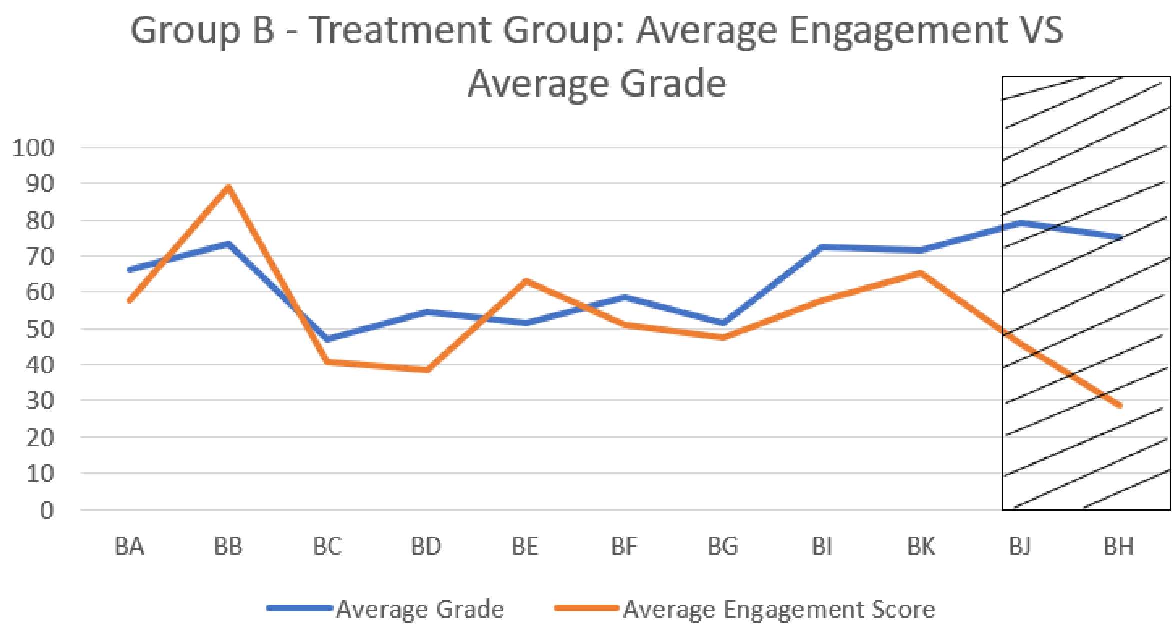


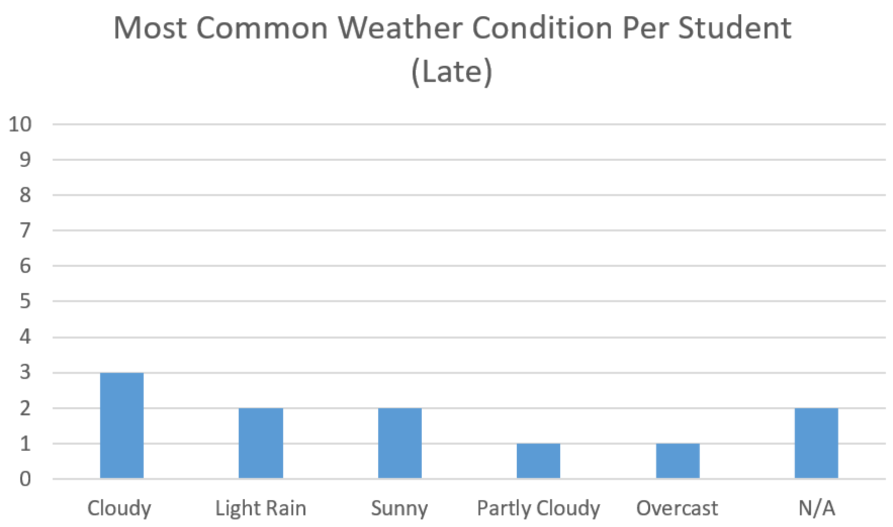
Figure 7.6 Group B Average Engagement and Grade per student

Figure 7.6 presents the data per student for Group B. The data presented produced an initial correlation coefficient *R* of 0.22, illustrating no real correlation between the student engagement measure and academic performance. Hardware issues became apparent after interviewing the students that produced a wide margin between values. Both students stated that their Bluetooth would not register their attendance even though they were present in classes. They mentioned this caused frustration and a tendency to disengage from the experiment. After verifying this claim by analysing the obtained attendance over the reported attendance of a lecturer, the data from students BJ and BH was classified as noise due to hardware issues. This thesis did not identify the origin of the hardware issue. Other students with the same phone did not reproduce the same issues, removing the possibility of a compatibility error due to the phone model and make.

After defining and removing data noise in the group, the correlation coefficient *R* increased to a healthy 0.71, presenting a strong uphill correlation, therefore proving the validity of the measure of engagement. In turn, this result verifies the effectiveness of the proposed framework, presented in Section 4.2. Summarising, though the average measures of engagement and the respective academic performance per group were similar in both groups, when analysing each student's measure in comparison to their academic performance, the data presents a new perspective that displays data noise and a great difference in correlation between the groups. The following section provides reasoning for the variance in correlation.

7.5.3 Weather and Student Engagement

It is important to outline the data presented only relate to the student behaviour of participants in Group B. Group A followed the conventional method of student engagement measure and therefore has no data in relation to environmental factors.



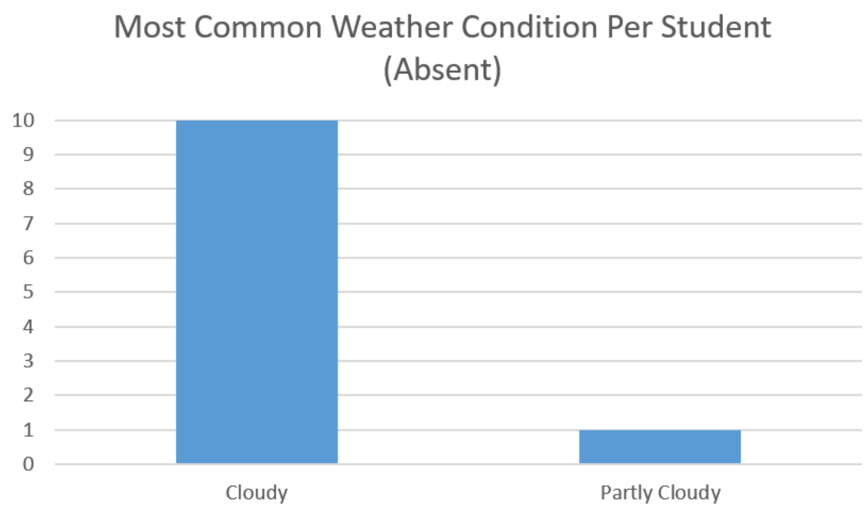


Figure 7.7 Common weather condition for lateness and absence

The obtained data highlighted no true correlation between weather condition and student engagement. The most recurring weather condition for absence and lateness was cloudy. Figure 7.7 displays the relative data. The N/A column represents the number of students that did not return a weather condition that was more popular. It is impossible to conclude that cloudy weather has a negative effect on student behavioural engagement, as the region could have seen more cloudy days due to the season. This fact sways data to this condition. Furthermore, the data obtained do not specify weather conditions for the days students were present and punctual.

This section, however, does prove that a Smart Serious Game can retrieve data from explicit sensor networks and attempt correlations. To prove any form of weather correlation with behavioural student engagement, a wide location-based experiment must be conducted, potentially at an international scale, allowing for a true variation of weather conditions and a larger dataset.

7.5.4 Evaluation of Results with User Feedback Responses

This thesis triangulates the data obtained from the experiments with data obtained from an interview questionnaire provided to participants at the end. The purpose of this exercise was to study the common beliefs of students against the data findings discussed in the previous sections. The interview questionnaire included open-ended questions for sourcing the qualitative responses of participants and comparing them to the quantitative data detailed previously.

Out of the total participants in both groups (*n=22*), 14 participants responded. Participants that presented abnormal data patterns were pursued to complete the questionnaire for understanding if their data was noise. From the respondents, six belonged to Group A, with the remaining eight belonging to Group B.

Question 1 investigates the effect of the experiment on student engagement, according to the participant's belief. From Group B, 75% felt there was a direct effect on their engagement. The remaining two participants stated no effect. This thesis did not set out to improve engagement. Though the majority that responded from this group believed there was an increase in engagement, there is no statistical proof of improvement from the quantitative data. From Group A, 2 out of 6 felt there was an improvement in their engagement. This finding is not surprising, as they did not interact with a game.

Question 2 sources the level of interaction. Group B mainly responded with phrases such as "I interacted with it as I attended university each day" and "I interacted with the game in every class I attended, I liked to gather the points and see how high I could get on the leaderboard." This validates the level of participation seen from the group in Section 7.4.1 and in turn explains the validity of the measure of engagement. Group A responded with phrases such as "7 or 9 times throughout the semester didn't interact due to coursework" or "I did not, I was in the group which did not use the game". There were also students in the group who responded with "I interacted with as many chances as I got". This validates the greater variance presented in this group and the overall reduction in participation. This variance coupled with the responses of participants provides an indication as to the effect of game immersion over conventional measures of engagement. It is interesting to note the self-awareness of students with their participation levels with the experiment.

Question 3 sourced the level of comfort students had with the technology they used as part of the experiment. It could be theorised that students in Group B would feel uncomfortable with the location-tracking element. Surprisingly, students from both groups unanimously stated there was no discomfort with the technology used. This promising result removes technology interaction as a factor to the quantitative measures obtained and validates the measures in both groups.

Question 4 follows up on the use of technology but questions the usability for the web application and Serious Game respectively. Overall, both groups felt that usability was very good and found the respective software easy to use and understand, supporting the responses to the previous question.

Question 5 focused on critical software bugs that could cause data noise in either group. Two participants from Group B reported issues with Bluetooth and obtaining an attendance mark even though they were present in lectures and practical sessions. The two students that stated this also presented a high variance between their student engagement measure and their academic performance. Their data was defined as noise, after investigating the data further and discovering the two students experienced technical difficulties that hindered their attendance and punctuality measures.

Finally, Question 6 gathered participant views on the overall experience with the experiment. Most participants from both groups chose not to add any further comments regarding any positive or negative experiences. Two students did suggest improving the data capture and data algorithm by accounting for how long students remained in a session, rather than if they attended alone. This should be investigated in future works, where a comparison can be made to the proposed data algorithm and a new iteration.

7.6 Chapter Summary

This chapter presents the findings of this research analysis, illustrated through data and statistical analysis. Summarising, comparing the group averages of student engagement and academic performance respectively, indicated a valid measure of engagement but did not provide statistical validity. Pursuing stronger validation, this project analysed the correlation coefficient R between each student and their academic performance per group. This analysis technique uncovered data noise in each group and showed a variance between each group and the validity of the measure. To explain this variance, this thesis investigated participant response rates per group and concluded that game immersion positively affect response rates. The aforementioned conclusively validated the measure of student engagement utilising a Smart Serious Game and a data algorithm, and in turn, validated the framework produced for combining Serious Games and the Internet of Things.

It is important to note the data presented did not validate the behavioural change or an increase in student engagement as an effect of gameplay. This was proved using triangulation to validate the quantitative statistical findings against the qualitative data obtained from exit interview questionnaires. This thesis did not intend to alter behaviour, increase student engagement or investigate the effect of Smart Serious Games on motivation. Such findings would require further research and a tailored background literature review. However, the presented framework for combining Smart Serious Games can be used to investigate these research topics as it is application neutral. The following chapter highlights the contributions of this thesis, suggests future directions for this research and concludes on the undertaken research.

CHAPTER 8 – CONCLUSIONS AND FUTURE WORKS

8.1 Introduction

This chapter discusses the contributions of this thesis and focuses on how the novelty of the thesis is validated through the experiments presented in the previous chapter. Furthermore, this chapter details the future directions of this thesis, considering research limitations. As the proposed framework of this thesis is adaptable, the scope of further research is great with impact on games, Serious Games, edutainment and gamification applications that combine their systems with the Internet of Things.

Finally, this chapter provides the concluding remarks of this thesis, highlighting all key elements of research and summarising the content of the thesis. The research novelty and contributions are revisited in relation to the successful completion of this thesis.

8.2 Contributions

This thesis identified a gap in the existing literature in relation to the combination of Serious Games and the Internet of Things. Current research has defined this combination as Smart Serious Games (Favorskaya et al. 2015). Further research into this academic field has proposed applications or application driven frameworks that are not adaptable in nature (Konstantinidis 2017; Garcia-Garcia et al. 2017; Kim 2017). This thesis addresses this issue by proposing a modular and adaptable framework for Serious Games and the Internet of Things. The proposed framework is validated through a semester-long experiment on a Smart Serious Game developed through it. The success of the Smart Serious Game mirrored the effectiveness of the proposed framework in producing Smart Serious Games of a variety of applications.

This thesis also contributes suggested adaptations to topologies for Serious Games and the Internet of Things to the academic field. The reconsidered topologies are a result of a literature survey of online networks for games and topologies for the Internet of Things. No new topologies were suggested; however, new devices and applications were included in existing topologies. In turn, this produced a set of requirements that need to be adhered to when considering a topology for Serious Games and the Internet of Things.

Finally, for validating the proposed framework, this thesis developed a data algorithm that quantifies elements of behavioural engagement and translates them into game points. This algorithm provides a foundation for future directions where student engagement is measured solely through computational and interconnected devices, providing proactive and reactive outcomes to the students that utilise these systems.

8.3 Future Directions

There are a number of future directions of research originating from this thesis. In Section 7.5.3, this thesis discussed the importance of including new environmental data sources to investigate the correlation of environmental data and student engagement. Additionally, new environmental data combined with the presented framework opens the potential for investigating the effects of environmental events on behavioural change, such as motivation, as the presented framework is application neutral and it is ideal for instantiating this type of research.

Furthermore, this thesis proposes the inclusion of time spent in class as a variable to be processed by the data algorithm to investigate a potential improvement in student engagement measure as a future direction. This data could be inputted into the data algorithm as an additional variable. This can improve the algorithm's accuracy and increase the correlation coefficient R between student engagement and academic performance. Though this variable could improve the performance of the algorithm, the algorithm remains statistically validated in its current form, and can conclusively be considered as a novel contribution to the academic field. Improving the measure would strengthen future research in adapting this solution as a predictive mechanism that highlights students at risk of underperforming academically before they submit their assignments.

Future directions of this thesis can accommodate for students that choose to learn from distance. Virtual Learning Environments and Open Courses present a new format of learning, where behavioural engagement cannot be measured through attendance or punctuality. This can be achieved by accounting for the background of the student and the level of the material being covered. This can be fed into the system through API sources or learning analytics systems in conjunction with Internet of Things devices. Additional factors that can be considered include class size, which can affect students with social anxiety.

Continuing, this thesis focuses on the combination of Serious Games and the Internet of Things, however, the proposed framework can be adapted to accommodate for other game domains by manipulating the modules that relate to game technologies. As such this thesis recommends utilising the framework in future directions to combine gamification, edutainment and game technology with the Internet of Things. As the framework is application neutral, the application of future works would be irrelevant.

This thesis suggests the future direction of forming a modular component library, accompanied by an ontology that defines the relative software components and outlines their relationship. This could benefit developers of Smart Serious Games to reduce development time and costs.

Additionally, this thesis proposes future works that investigate if an adapted version of this application can increase student engagement or positively alter human behaviour elements such as motivation, and consider new participant demographics, noting if Smart Serious Games can be adopted as well in different cultures. Again, the presented framework would form the foundation for such future works.

Standardisation promises a future in the Internet of Things where resources from a variety of services can interoperate on an application level. For Smart Serious Games, this would allow input from unconventional data inputs to games today. In the future, the data obtained from a car, a smart meter, online shopping habits could be analysed, and the player's carbon-footprint could be determined. Currently, standardisation is an issue, with limited interoperability, limiting the potential for applications (Miorandi et al. 2012).

This thesis proposes further research to enhance standardisation. The standardisation of security policies and cyber-security presents a further challenge. Security presents challenges in different aspects including wireless networks, standards and cloud. Wireless Sensor Networks are commonly utilised in Internet of Things solutions, and Smart Serious Games are no different. The low energy requirements of Wireless Sensor Networks require further research for more fitting security mechanisms (Christin et al. 2009). Security policies require standardisation to allow multiple devices of various type to communicate securely and maintain data privacy (L. Da Xu et al. 2014). Literature by D. Misha et al. (2014), into cloud gaming uncovered the need for further research in cloud security for games before the technology can be widely adopted.

8.4 Conclusion

This thesis began by identifying a lack of an application neutral framework for combining Serious Games and the Internet of Things. The undertaken literature review into Student Engagement emphasised the value and impact such a framework presents to the academic community, confirming its novelty.

Before developing a framework, this thesis investigated Serious Games, their applications and the presence they have in Student Engagement. Additionally, it investigated the Internet of Things, its applications, and how the ecosystem could network with a Serious Game. After reviewing existing frameworks into Serious Games and service-specific frameworks on Smart Serious Games, this project decided to produce a modular framework to represent the combination of Serious Games and the Internet of Things. The modular nature of the framework allows future projects to adapt it to a service-specific version.

Furthermore, this thesis uncovered a lack of research surrounding the network requirements and practices for developing Smart Serious Games. A literature review into Internet of Things topologies and online game architectures identified existing network solutions that are compatible for this domain of games. As this thesis utilises Student Engagement as a case study for validating the presented framework, it does not include the necessary background literature to investigate a potential increase in student engagement or any form of behavioural manipulation. These research topics form part of the future works.

This thesis presents three key contributions, a modular framework, a computer algorithm for measuring student engagement, and compatible topologies for developing Smart Serious Games. All three contributions are novel as they have an impact in future research and value in reducing the required research for developing Smart Serious Games, analysing student engagement through real-world events, and understanding the network requirements when combining the two domains.

The presented modular framework was successfully validated after rigorous data analysis including a comparison between groups, correlations performed through statistical algorithms and data triangulation. Additionally, data analysis highlighted research limitations and avenues for future works, elements discussed in the previous sections of this chapter.

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APPENDIX

1. Game Point Allocation from Sensor Network Activity

Game Objectives (Weekly Scores)

Attendance (Behavioural Engagement)				*Questionnaire Score* (Emotional amd Cognetive Engagement)	**Engagement Factor**
Punctuality	*Score*	*Classes*	*Score*	*Total from user + Total from Academic / 2*	*Attendance + Engagement over a week/ 2*
Over 10 minutes late	2	Attended a class	5		
Between 5 and 10 minutes late	3	Attended all classes in a week	10		
Less than 5 minutes late	5	Attended all classes in a month	20		
Less than 5 minutes late in a week	10	Attended all classes in a semester	40		
Less than 5 minutes late in a month	20				
Less than 5 minutes late in a semester	40				

Weekly Scores (Re-occuring)

	Personas	**Attendance**	**Questionnaire**	**Factor**
	Engaged	120	80	100
WEEK 1	Neutral	105	60	83
	Disengaged	24	10	17

Weekly Scores (Randomised)

	Personas	**Attendance**	**Questionnaire**	**Factor**
	Engaged	38	40	39
WEEK 2	Neutral	73	54	64
	Disengaged	50	20	35

Appendix 1 - Points rewarded to players based on their attendance activity captured by the wireless sensor network

2. Engagement Questionnaire

No.	Question
1	I adhere to the lecturer’s instructions during the session
2	I try my hardest to understand and /or implement what I’m taught
3	If I don’t understand something, I will persistently try to work it out
4	When in a lecture or lab, I very rarely get distracted
5	I find the material taught on my programme very interesting
6	I stay engrossed in all lecture or lab activities
7	Overall, I am satisfied with the material delivered on the course
8	I am proud of achieving on the programme
9	I tend to complete the optional lab tasks and/or further reading
10	I strategically breakdown tasks to further my understanding of lecture or lab material

Appendix 2 - Questions included in engagement questionnaire

3. End of Experiment Questionnaire

No.	Question
1	Do you feel this project had any effect on your engagement with the programme (positive or negative?). Please explain your answer.
2	Please describe how often you have interacted with the game or web app this semester. If you did not please explain why:
3	Did the technology used in this project (mobile game, remote attendance monitoring) make you feel uncomfortable? If so, why?
4	How would you describe the usability of the application you were involved in (electronic questionnaires or game)?
5	Did you stumble upon any bugs/errors that restricted or hindered the use of the application you interacted with (electronic questionnaires or game)?
6	Is there anything you would like to disclose about your experience with this research project (positive or negative)?

Appendix 3 - Questions included in interview questionnaire