Towards a Serious Game Approach for Mold Prevention Education in New Zealand Homes

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by

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Abstract

Indoor air pollution remains a major determinant of human health and well-being, with residential mold widely recognized as one of New Zealand's most persistent public health concerns. Long-term exposure to damp and moldy homes is associated with asthma, allergies, respiratory infections, and other chronic conditions, disproportionately affecting children and low-income households. Despite ongoing public awareness efforts, understanding of effective mold prevention remains limited, and conventional educational approaches have demonstrated only modest and short-lived behavioral impact. This doctoral research addresses this gap by developing and evaluating a serious game aimed at improving mold prevention education among the general public in New Zealand. The research comprised four connected studies: i) a systematic review of gamification in air-quality education, ii) the design and prototyping of a serious game, iii) an experimental comparison between a serious game and video-based learning, iv) and a multi-group Structural Equation Modeling (SEM) analysis to examine underlying learning mechanisms. Results from the controlled experiment showed that although both the game and video significantly improved immediate knowledge, the serious game improved higher intrinsic motivation, better perceived usability, and lower task load. Importantly, only participants in the game condition maintained their knowledge after four weeks, indicating stronger knowledge retention. Behavioral intention improved in both groups without a significant difference, suggesting that knowledge gains alone may not be sufficient to drive sustained behavioral change without continued reinforcement. The SEM analysis revealed distinct media-specific pathways. In the game condition, prior knowledge strongly predicted post-test knowledge, indicating that interactive features may activate learners' existing cognitive structures. In contrast, the video condition relied more heavily on usability-driven motivation pathways that subsequently influenced post self-efficacy. These findings suggest that interactive and non-interactive media support learning through different cognitive and motivational processes. This thesis contributes to indoor environmental health by developing and empirically validating a theory-informed serious game for residential mold prevention in New Zealand. It integrates Gamification Design Theory and Self-Determination Theory within a multi-group SEM framework to explain how learner and system factors influence learning outcomes. Empirical findings demonstrate that serious games enhance intrinsic motivation, perceived usability, and knowledge retention compared with video-based learning. Practically, it delivers a validated and scalable educational tool to support serious games in mold prevention and environmental health education.

Dedication

To my beloved mother and father,

whose unwavering love, sacrifices, and support have been the foundation of my journey. Your encouragement has been my constant source of strength.

And to my dear brothers,

for their companionship, motivation, and belief in my abilities. You have each played a unique role in shaping my path.

This work is dedicated to you all, with deepest gratitude and love.

Epigraph

"If I have seen further, it is by standing on the shoulders of giants."

Sir Isaac Newton

This work reflects the many insights, discoveries, and sacrifices made by the great thinkers, researchers, and educators who came before me. Their knowledge has paved the way for my inquiry, inspired my questions, and shaped my understanding of the topic.

To those giants in science, academia, and life
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Abbreviations and Acronyms

AR	Augmented Reality
VR	Virtual Reality
CD	Core Drive
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CBA	Cost-Benefit Analysis
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IMI	Intrinsic Motivation Inventory
TLX	Task Load Index
NH_3	Ammonia
NO_2	Nitrogen Dioxide
NZ	New Zealand
O_3	Ozone
OAP	Outdoor Air Pollution
PM	Particulate Matter
RH	Relative Humidity
SCT	Social Cognitive Theory
SDT	Self-Determination Theory
NMSUS	NASA Modified System Usability Scale
TVOC	Total Volatile Organic Compounds
UVI	Ultraviolet Index
UX	User Experience
VOC	Volatile Organic Compounds
WHO	World Health Organization
SEM	Structural Equation Modelling
CFA	Confirmatory Factor Analysis
AVE	Average Variance Extracted
CR	Composite Reliability
HTMT	Heterotrait-Monotrait Ratio
NZGBC	New Zealand Green Building Council
BRANZ	Building Research Association of New Zealand

MBIE	Ministry of Business, Innovation and Employment
SD	Standard Deviation
M	Mean
β	Beta (Standardized Coefficient)
CI	Confidence Interval
df	Degrees of Freedom
p	p-value (statistical significance)

List of Peer-reviewed Publications

This thesis consists of seven chapters, each based on a research article that has been either published or submitted to internationally recognized peer-reviewed journals. Aside from minor textual revisions and formatting adjustments, the chapters are presented in their original form as published, accepted, or submitted for publication.

Publication 1

Chapter 3: A Systematic literature review on the application of gamification in air quality education. The content of this chapter is extracted from:

- Baghaei Daemei, A., Lovreglio, R., Feng, Z., Paes, D., & Miller, C. (2025). *Gamification for air quality education: A systematic literature review*. Building and Environment, 112526. https://doi.org/10.1016/j.buildenv.2025.112526.

Publication 2

Chapter 4: Developing and prototyping a serious game aimed at educating individuals on mold prevention techniques in residential buildings. The content of this chapter is extracted from:

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Publication 3

Chapter 5: Assessing the effectiveness of game-based learning compared to video-based learning. The content of this chapter is extracted from:

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Publication 4

Chapter 6: Understanding how learner factors and system-related factors predict learning outcomes and behavior change over time. The content of this chapter is extracted from:

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List of Awards

1. CIB Sebestyén Future Leaders Award, 2025 (Shortlisted)
2. Future Thinker of the Year: New Zealand Green Building Council, 2025 (Shortlisted)
3. Best Presentation Award, 47^{th} AUBEA Conference, Victoria University, Melbourne, Australia, 2024
4. Best Paper Award, 13^{th} International Conference on Engineering, Project, and Production Management (EPPM), Massey University, Auckland, New Zealand, 2023

Chapter 1

Introduction

This chapter introduces the background and motivation for developing an educational game designed to enhance awareness of indoor air quality and mold prevention in New Zealand homes. Mold growth remains a common yet often overlooked issue in the country's aging and poorly insulated housing stock, with profound implications for public health. While traditional learning methods, such as seminars or videos, have been used in the past, they often struggle to keep people engaged or inspire meaningful behavioral change. This chapter lays the foundation for the research by providing essential context and framing the overall study. It introduces the background and rationale behind the investigation, articulates the research problem, and outlines the scope of the study. The chapter also presents the research aim and objectives, highlighting the key questions that guide the inquiry. Furthermore, it highlights the significance and expected contributions of the research to the fields of environmental education, gamification, and indoor air quality. The chapter concludes with an overview of the thesis structure, guiding the reader through the subsequent chapters.

Chapter 1: Introduction

1.1 Background and Context

In our rapidly evolving world, air pollution, which has given rise to the forefront of environmental concerns, poses significant threats to public health (Manisalidis et al., 2020b; Whitmee et al., 2015). Being exposed to elevated air pollution levels, in one sense, can lead to various adverse health consequences, including respiratory infections, heart problems, and lung cancer, which causes almost seven million deaths worldwide per annum (Lelieveld et al., 2015; Silva et al., 2017). These pollutants, often generated by human activities such as industrial processes, transportation, and energy production, can have severe consequences on both the environment and human health (Li et al., 2019). The primary pollutants include particulate matter (PM), nitrogen oxides (NO_X), sulfur dioxide (SO_2), carbon monoxide (CO), and volatile organic compounds (VOCs), among others. As these pollutants accumulate in the air, they contribute to the deterioration of air quality, leading to a range of adverse effects (Burnett et al., 2018). Additionally, air pollution plays a significant role in climate change by contributing to the greenhouse effect and global warming (Ramanathan & Feng, 2009). Human health is also profoundly affected, with respiratory and cardiovascular problems, as well as increased risks of cancer, being linked to prolonged exposure to polluted air (Turner et al., 2020). Addressing air pollution requires concerted efforts at local, national, and global levels to regulate emissions, promote cleaner technologies, and raise public awareness about the importance of air quality (Kelly & Fussell, 2015). Recognizing the interconnectedness of air pollution and its consequences underscores the urgency of adopting sustainable practices and policies to safeguard both the environment and human health (Li et al., 2018).

Indoor Air Quality (IAQ), on the other hand, is a critical aspect of environmental health, intimately linked to the broader issue of air pollution (González-Martín et al., 2021; Jones, 1999). While the term "air pollution" often conjures images of industrial smokestacks and vehicle emissions, it is essential to recognize that indoor spaces can harbor their own unique set of pollutants, which significantly affect the well-being of occupants. Exposure to air pollutants also manifests health impacts in both short and long term, with particularly severe consequences for individuals who are already unwell (Unni et al., 2022). Vulnerable groups, including children, pregnant women, the elderly, and those with limited financial resources, are at a heightened risk (WHO, 2019). The repercussions of air pollution extend beyond immediate discomfort, which means it brings about irritation to the nose, throat, eyes, skin, headaches, dizziness, or nausea (Bernstein et al., 2008; Manisalidis et al., 2020a), emphasizing the urgent need for holistic solutions (Brunekreef & Holgate, 2002; Kampa & Castanas, 2008). Thus, it is crucial to educate individuals about the sources and consequences of air pollution, empowering them with the knowledge to make informed decisions and change their behaviors to promote public health and well-being (Aslam et al., 2023; McCarron et al., 2023; Steinemann et al., 2017).

Educating people about IAQ is of paramount importance due to the direct and profound impact it has on human health (Moreira et al., 2022). The air we breathe indoors can be laden with a variety of pollutants, including PM, VOCs, and other harmful substances (Fan et al., 2024). Understanding these potential health risks empowers individuals to take proactive measures to minimize exposure and protect their respiratory and overall well-being (Kim et al., 2024). Particularly concerning is the fact that poor IAQ can lead to a spectrum of health issues. Respiratory problems, such as coughing, wheezing, and aggravated asthma symptoms, are commonly associated with prolonged exposure to indoor pollutants (Hao et al., 2024). Additionally, the presence of VOCs emitted from household products and building materials can contribute to headaches, dizziness, and irritation of the eyes, nose, and throat (Cheng et al., 2024). By disseminating information about these health consequences, public awareness campaigns can motivate individuals to adopt practices that enhance the quality of air within their homes and workplaces (P. Li et al., 2024).

The recent scientific community has noted heightened pollution levels within buildings compared to outdoor environments, even in densely populated urban centers (IQAir, 2018; MANA, n.d.; Sanalife, 2022). Additionally, Kankaria et al. (2014) reported that the impact of IAQ can be up to 10 times worse than that of OAP. Moreover, individuals spend approximately 90 percent of their time indoors, magnifying the potential health risks associated with IAP (Tran et al., 2020). Based on a report released by WHO (2023): *"Each year, 3.2 million people die prematurely from illnesses attributable to the household air pollution. Particulate matter and other pollutants in household air pollution inflame the airways and lungs, impair immune response, and reduce the oxygen-carrying capacity of the blood."* Air pollution poses significant risks to numerous New Zealand residents, particularly children. In 2016, anthropogenic air pollution in New Zealand led to:

- Approximately 3,317 premature fatalities among individuals aged 30 and above.
- Roughly 13,155 hospitalizations due to cardiovascular and respiratory ailments, including 845 cases of childhood asthma.
- An estimated 13,229 incidents of childhood asthma.

- Approximately 1.75 million days of restricted activity, during which individuals could not engage in their usual activities due to air pollution.

If there were no human-made air pollutants such as PM2.5 or NO2 in New Zealand, around 3,300 deaths could have been prevented in 2016. This would have accounted for approximately 11% of all deaths recorded in New Zealand that year. According to the data released by Environmental Health Intelligence New Zealand (2022), in March 2020, the New Zealand Government implemented an elimination strategy for COVID-19, which included moving the country to Alert Level 4 (Lockdown) on 25 March 2020. This strategy also involved temporary border closures, quarantine mandates, widespread community testing, school closures, and rigorous contact tracing efforts. These stringent public health measures aim to control the spread of the virus and protect public health. The impact of these measures on asthma hospitalization rates in children aged 0–14 years was observed in both 2020 and 2021. According to the factsheet released by Environmental Health Indicators (2020), "In 2018, there were 7,182 asthma-related hospitalizations (including wheeze) among children aged 0–14 years in New Zealand. The number of asthma hospitalizations increased between 2006 and 2018." It is also noted that various environmental triggers, such as exposure to household pollutants (e.g., dust mites, animal fur, pollen, and mold), may contribute to asthma.

Dyson has released data collected from January to December 2022 from 3.4 million internet-connected air purifiers worldwide, with 11,844 units in Aotearoa, New Zealand (Dyson, 2024; Rutledge, 2024). The Global Air Quality Connected Data project examined two types of pollutants: PM2.5, which are particles smaller than 2.5 micrometers, and VOCs, emitted from various sources such as aerosol sprays and furniture. PM2.5 particles, smaller than dust and pollen, are deemed to be inhaled and can reach the lungs. WHO's 2021 guidelines recommend keeping annual PM2.5 exposure levels below five micrograms per cubic meter ($\mu g/m^3$). In 2022, New Zealand's annual indoor average, according to Dyson, was 6.85 $\mu g/m^3$, with the highest levels during colder months, notably May (8.46 $\mu g/m^3$), and the lowest in February (4.46 $\mu g/m^3$). Indoor PM2.5 levels peaked at 10 pm (6.885 $\mu g/m^3$) and were lowest at 5 am (3.215 $\mu g/m^3$), with VOCs reaching their highest levels at 11 pm. Air pollution poses significant health risks, with long-term exposure linked to an increased risk of respiratory diseases, and acute exposure exacerbating existing conditions. Respiratory disease ranks as New Zealand's third leading cause of death, with higher hospitalization rates among Pacific and Māori peoples (Dyson, 2024; Rutledge, 2024).

Referring to a research report by Consumer (2023), "*According to a 2015 BRANZ survey, more than half of New Zealand rental houses had visible mold. It is often caused by moisture issues in the home and may be beyond your control to manage*." Having more resilient houses could improve this. Last year's Housing in Aotearoa: 2020 report, by Stats NZ and the Building Research Association, says about 28,000 homes were reported to be constantly damp and always have visible mold (Anthony, 2020). Emphasizing the fact by mentioning a study performed by Keall et al. (2012), "estimated there was a corresponding rise in the experience of wheezing or asthma." Cold, damp housing can result in higher seasonal mortality rates and higher incidence of both cardiovascular and respiratory disease. In 2018, about 28,000 homes in New Zealand were reported to be constantly damp and always have visible mold over an A4-sized (StatsNZ, 2020). Figure 1.1 shows the correlation between damp and moldy houses in Auckland.

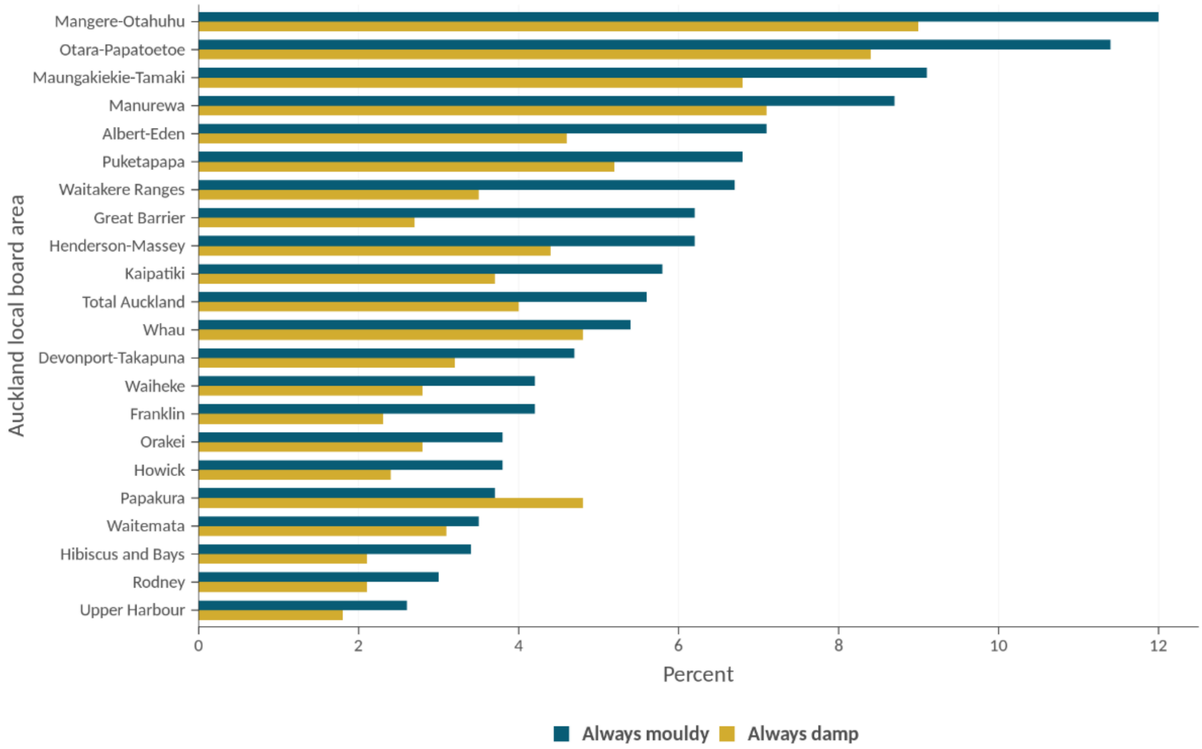

Figure 1.1: Proportion of dwellings constantly damp or moldy, by Auckland local board area

Therefore, it is evident that addressing mold issues in homes in New Zealand is urgent. Extensive scientific research has consistently shown a direct correlation between poor indoor air quality and health problems in residences with mold contamination (Graham, 2023; Lewis et al., 2023; Morawska et al., 2024; Nature Editorial, 2023; Stokstad, 2004). The scope of this study is to address IAP by focusing on mitigating mold growth through behavioral interventions (or Mold Assessment). This includes identifying and implementing various strategies, as well as understanding the primary sources of mold growth, to change their behavior and reduce indoor moisture levels. The study will explore and recommend action plans that individuals can adopt to effectively minimize moisture accumulation indoors, thereby mitigating the conditions conducive to mold growth.

1.1.1 Game-Based Learning and Serious Games

Game-based learning is an instructional approach that integrates games with explicit educational objectives to facilitate knowledge acquisition, skill development, and behavior change (Douglas & Brauer, 2021; Johnson et al., 2016). It is grounded in the premise that learning is enhanced when individuals actively engage with content through structured challenges, feedback, and meaningful interaction rather than through passive information exposure (Oliveira et al., 2023). Within game-based learning environments, learners typically assume an active role in exploring scenarios, solving problems, and making decisions, which supports deeper cognitive processing and improved knowledge retention (Behl et al., 2024; Boso et al., 2020; De Jans et al., 2017). In contrast to purely entertainment-focused games, educational game-based interventions are intentionally aligned with pedagogical goals and assessment outcomes, ensuring that engagement serves a clear instructional purpose (Buckley & Doyle, 2016).

The theoretical foundations of serious games draw from constructivist learning theory, experiential learning, and motivational psychology (Barna & Fodor, 2018; van Roy & Zaman, 2018; Yildirim, 2017). From a constructivist perspective, knowledge is actively constructed through interaction with the learning environment rather than transmitted directly from instructor to learner (Bada & Olusegun, 2015; Palincsar, 2012). Serious games operationalize this principle by embedding learners within simulated contexts where they can experiment, receive feedback, and refine their understanding iteratively (Richard N Landers, 2014). In parallel, Self-Determination Theory explains how well-designed game environments support intrinsic motivation by satisfying learners' needs for autonomy, competence, and relatedness (Deci & Ryan, 2012; Ryan & Deci, 2024). When these psychological needs are met, learners are more likely to demonstrate persistence, engagement, and sustained learning effort (Deci et al., 2017).

A substantial body of empirical research supports the educational effectiveness of game-based learning across domains such as health education, environmental awareness, and professional training (Connolly et al., 2012; Schrader, 2023). Studies consistently report improvements in learner motivation, engagement, and in many cases knowledge outcomes when serious games are used appropriately (Buckley & Doyle, 2016). Key design features contributing to these outcomes include progressive challenge structures, immediate formative feedback, goal-oriented tasks, and interactive storytelling (Mekler et al., 2017). These elements help maintain learner attention while also scaffolding the learning process (Plass et al., 2015). Importantly, the effectiveness of game-based learning is highly dependent on pedagogical alignment; poorly designed games that prioritize entertainment over learning objectives may fail to produce meaningful educational gains (Clark et al., 2016).

Game-based learning typically involves integrating familiar game components (e.g., points, rewards, badges, challenges, and interactive storytelling) into learning activities to increase motivation, enjoyment, and sustained participation (Alsawaier, 2018; Zichermann & Cunningham, 2011). These elements work by tapping into psychological drivers such as the desire for achievement, competition, curiosity, and personal growth (Buckley & Doyle, 2016; Sharma et al., 2024). When carefully designed, game mechanics help structure challenges, guide learner progression, and create a sense of accomplishment, making the educational experience both engaging and meaningful (Mekler et al., 2017).

The adoption of such approach has increased substantially with the expansion of digital technologies, smartphones, and online platforms (Hong et al., 2024; Liuyufeng. Li et al., 2024). Organizations in fields such as education, healthcare, and industry utilize gamified tools to enhance engagement, improve learning outcomes, and promote behavioral change (Almeida et al., 2023; Sardi et al., 2017). In the context of environmental health, integrating air-quality education into interactive game experiences can motivate individuals to better understand pollution, recognize risks, and adopt improved habits (Boso et al., 2020; Shi et al., 2022).

Game-based learning offers a powerful and flexible strategy for increasing awareness, motivation, and user engagement across a wide range of topics (Kogut et al., 2023; Seaborn & Fels, 2015). Its ability to capture attention, personalize learning, and promote active participation makes it especially suitable for supporting public education efforts on indoor air quality and mold prevention. Serious games, also known as educational games, are interactive experiences designed to deliver instructional content while actively engaging users in gameplay (Susi et al., 2007; Triantafyllou et al., 2025). Unlike entertainment-focused video games, they are created with clear learning objectives and aim to impart knowledge, develop skills, or support behavior change (Connolly et al., 2012).

1.1.2 Rationale for Using Serious Games

Educating individuals about air quality is paramount due to its significant and far-reaching implications on public health and the environment (Marcotte, 2017). Also, they can actively participate in efforts to control and manage air pollution (Auerbach & Flieger, 1967). If people become more aware of the importance of air pollution, it is more likely to prompt positive changes in both individual behavior and public policies (Kelly & Fussell, 2015). This increased awareness has the potential to drive actions to mitigate pollution, resulting in a cleaner environment and a healthier population (Arcury, 1990; Wang et al., 2016). Therefore, boosting education, training, and increasing public awareness can lead the public to achieve goals related to environmental pollution (Manisalidis et al., 2020a).

Many people are unaware of the invisible threats in the air we breathe, and raising awareness is crucial for informed decision-making and behavior (Barbosa et al., 2017). Moreover, informed citizens are more likely to advocate for policies and practices that contribute to cleaner air, creating a collective impact on a global scale, resulting in reduced health risks, such as lower rates of respiratory conditions like asthma, improved overall well-being, and a healthier future for communities worldwide (Moreira et al., 2022). To this end, a practical educational approach to air quality is needed. An innovative approach gaining momentum is the incorporation of gamification into air quality education. Gamification transforms learning about air quality into an engaging and interactive experience by applying game elements and offering various features, such as real-time data collection (Polychronidou et al., 2019). Through gamified applications and platforms, individuals can participate in challenges, quizzes, and simulations that simulate real-world scenarios related to air quality (Stamatiadou et al., 2023).

The necessity to educate the public about the sources and consequences of air pollution is closely tied to the concept of Environmental Health Literacy (Raufman et al., 2020). As highlighted by the National Institute of Environmental Health Sciences (NIEHS) in 2014 (Lindsey et al., 2021), Environmental Health Literacy is an evolving concept that integrates theories from risk communication, environmental health science, behavioral science, evaluation, communications, public health, and the social sciences (Kim et al., 2024). Environmental Health Literacy refers to an individual's ability to understand, interpret, and apply information about environmental factors that can affect health. It involves not only acquiring knowledge about the links between environmental exposures and health outcomes but also the capacity to make informed decisions and take actions to protect one's health and the well-being of the community (Finn & O'Fallon, 2017). Enhancing environmental health literacy is crucial for empowering individuals and communities to make informed decisions that contribute to healthier living environments and sustainable practices. It plays a crucial role in fostering a sense of responsibility for environmental stewardship and promoting overall well-being (Finn & O'Fallon, 2017).

Building on this rationale, it is essential to consider the limitations of traditional educational methods and the unique advantages of game-based interventions. Traditional educational methods (e.g., brochures, factsheets, or passive video lectures) often fail to engage non-expert audiences meaningfully (Smith et al., 2024). As a result, they limit long-term retention and weaken the translation of knowledge into real-world mold-prevention practices (Hasanica et al., 2020). Indeed, conventional static formats tend to be limited when the audience lacks prior motivation or domain familiarity, especially for complex topics like IAQ (Pulimeno et al., 2020).

In contrast, serious games and gamified learning environments create an interactive, decision-based, and simulation-rich context that better mirrors real-life situations, thus promoting deeper cognitive processing, emotional engagement, and behavioral intention (Chen et al., 2025; Koivisto & Hamari, 2019). Empirical studies support this: a recent systematic review identified dozens of serious games for environmental education whose reported outcomes include increased knowledge, attitudinal shifts, and pro-environmental behavioral intentions (Chen et al., 2024; Tan & Nurul-Asna, 2023).

Further, when digital game-based learning is applied to environmental topics, learners often show significantly greater gains in environmental literacy and sensitivity compared to traditional web-based instruction (Wahlström, 2025). Importantly, contemporary reviews emphasize that well-designed gamified interventions, characterized by meaningful feedback, autonomy, real-world scenario simulation, and iterative learning loops, lead to stronger engagement and deeper cognitive involvement (Ryan & Deci, 2020).

These features enable serious games to outperform static instructional content in sustaining learner interest and motivating behavioral change over time (Hamari et al., 2014; Plass et al., 2015). Therefore, in the context of mold prevention and IAQ, a serious game offers a theoretically and empirically grounded alternative, making it far more likely that participants will internalize knowledge and translate it into healthier behaviors in their own homes (Janakiraman et al., 2021).

1.2 Problem Statement

Gap 1: Despite growing academic interest in gamification for air-quality education, the current body of research lacks a consolidated and comprehensive overview. While individual studies have investigated gamified interventions for indoor or outdoor air quality, no systematic review has synthesized these efforts into a unified framework. The literature remains fragmented in terms of audiences, mechanics, methods, and evaluation practices. This fragmentation highlights the need for a structured synthesis to map existing work, identify trends, and clarify the scope of current research (Addressed by Objective 1).

Gap 2: Although gamification has demonstrated potential for enhancing engagement and promoting behavior change across various educational domains, its application specifically to mold prevention remains underexplored. For example, various studies have compared the effectiveness of digital and innovative methods (i.e., gamification) in safety training, such as for earthquake preparedness (Çoban & Göktaş, 2023; Feng et al., 2021; Mirsoleymani et al., 2022), construction accidents and fire safety (Kazar & Comu, 2021; Lovreglio et al., 2021), construction site safety (Lu et al.; Tagliabue et al., 2020), hazard detection (Cavalcanti et al., 2021; Mohd et al., 2019; Ren et al., 2022), risk management (Taillandier & Adam, 2018), and other general topics in the built environment (Ilbeigi et al., 2024; Lai et al., 2020; Villagrasa et al., 2014). However, no studies have compared game-based learning with traditional methods for mold prevention, nor have they assessed how effectively a game can transmit mold-prevention knowledge to the general public. Furthermore, no consistent curricular or content framework exists for a serious game tailored explicitly to mold-related IAQ education (Addressed by Objective 2).

Gap 3: Likewise, while gamification has been successfully applied to various fields (e.g., safety-training, earthquake preparedness, construction hazard identification, fire safety, etc.) the literature contains no experimental comparison between game-based learning and traditional educational delivery methods for mold-prevention, measuring variables like knowledge acquisition, retention, task load, usability, and behavioral change over time (Addressed by Objective 3).

Gap 4: Finally, a critical unresolved gap lies in the limited understanding of the psychological and system-related factors that underpin learning in gamified environments. Constructs such as motivation, self-efficacy, task load, and usability have been studied individually, but rarely within integrated theoretical models. Few studies employ causal frameworks, including SEM, to examine how these constructs interact and influence knowledge and behavioral outcomes over time. Without such mechanistic insight, the design and evaluation of gamified tools remain empirically driven rather than theory-informed (Addressed by Objective 4).

1.3 Research Aim and Objectives

This research aims to develop and evaluate a game-based learning approach to educate the general public about the sources, causes, and mitigation strategies of mold within residential buildings in New Zealand. The following objectives were formulated to achieve the aim of the research:

Objective 1: To identify the current understanding and application of gamification approaches for training individuals about air quality within the built environment. This objective sought to deepen the understanding of how gamification is being used to train individuals about air quality within the built environment. To explore this, the objective addresses eight structured research questions focusing on the context and learning goals of existing gamified interventions, the characteristics of their target audiences, the types of game elements used, delivery formats, reported outcomes, encountered implementation challenges, and theoretical foundations guiding their design.

Objective 2: To develop a game-based learning approach aimed at educating the general public about mold prevention through an engaging, interactive, and safe digital environment. The development focused on delivering educational content through a game-based learning experience that enhanced user engagement and facilitated the application of knowledge in real-world contexts. To ensure the effectiveness of the intervention, core principles of learning design, motivational theory, and gamification strategy were integrated into the game's structure. The objective also addressed the gap in existing educational tools by offering an accessible and contextually relevant platform that supports public awareness and behavioral change in response to mold prevention.

Objective 3: To evaluate the effectiveness of the developed serious game in comparison to traditional educational methods by measuring knowledge acquisition, knowledge retention, behavior change, intrinsic motivation, general self-efficacy, perceived cognitive workload, and user experience. This objective focused on evaluating the effectiveness of the developed serious game compared to traditional educational approaches. The evaluation examined multiple learning and behavioral dimensions, including knowledge acquisition, knowledge retention, intrinsic motivation, general self-efficacy, task workload, usability, and behavioral change. The findings from this objective helped to determine how interactive, game-based learning experiences influence both immediate learning outcomes.

Objective 4: To understand how learner factors (i.e., prior knowledge and self-efficacy) and system-related factors (i.e., usability, task load, and intrinsic motivation) predict learners' post knowledge and self-efficacy to influence learning and behavior change. This objective aimed to explore how various learner and system-related factors contribute to knowledge acquisition over time. By examining both direct and indirect relationships among these variables, the research sought to reveal the underlying mechanisms through which game-based learning supports sustained knowledge gain in the context of mold prevention education.

To provide structural clarity, the relationship between the central problem, the four research gaps, the corresponding objectives, and the eventual outputs is illustrated in Figure 1.2. The purpose of this figure is to make explicit the alignment between what was lacking in prior research or practice and what this thesis set out to achieve.

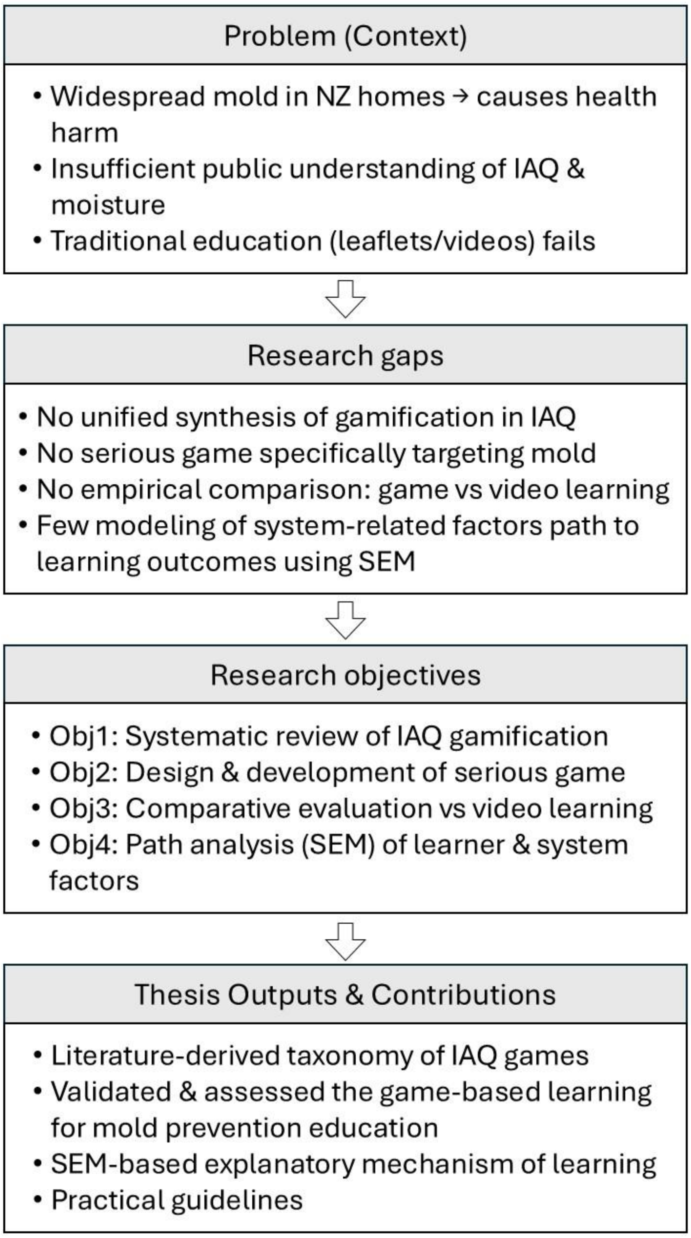

Figure 1.2: Logical mapping of the thesis flow

1.4 Thesis Structure

This thesis is organized into seven chapters, each corresponding to a specific phase of the research and, in most cases, a related peer-reviewed publication (see Figure 1.3).

- **Chapter 1** introduces the research background, problem statement, aim, and objectives. It also outlines the rationale for using serious games to address mold prevention education and presents this thesis structure.
- **Chapter 2** describes the research methodology, outlining the overall research methods associated with each research objective, philosophical approach, and data collection

methods used in the study. The chapter also details the ethical considerations and participant consent process.

- **Chapter 3** presents a systematic literature review on the application of gamification in air quality education. It identifies trends, game elements, learning objectives, target audiences, and theoretical frameworks, which inform the subsequent development phases.
- **Chapter 4** details the design and development of a prototype serious game for mold prevention in residential buildings. It covers the educational content, game mechanics, narrative, and verification through expert interviews and home visits.
- **Chapter 5** evaluates the effectiveness of the developed serious game compared to video-based learning. It reports on knowledge acquisition, motivation, self-efficacy, task load, usability, and behavioral change, based on experimental testing.
- **Chapter 6** investigates the relationships between learning outcomes, motivation, self-efficacy, usability, and task load using a structural equation modelling approach. It explores how these factors interact to influence sustained knowledge.
- **Chapter 7** concludes the thesis by summarizing key findings, outlining the contributions, providing practice recommendations, and identifying future research directions.

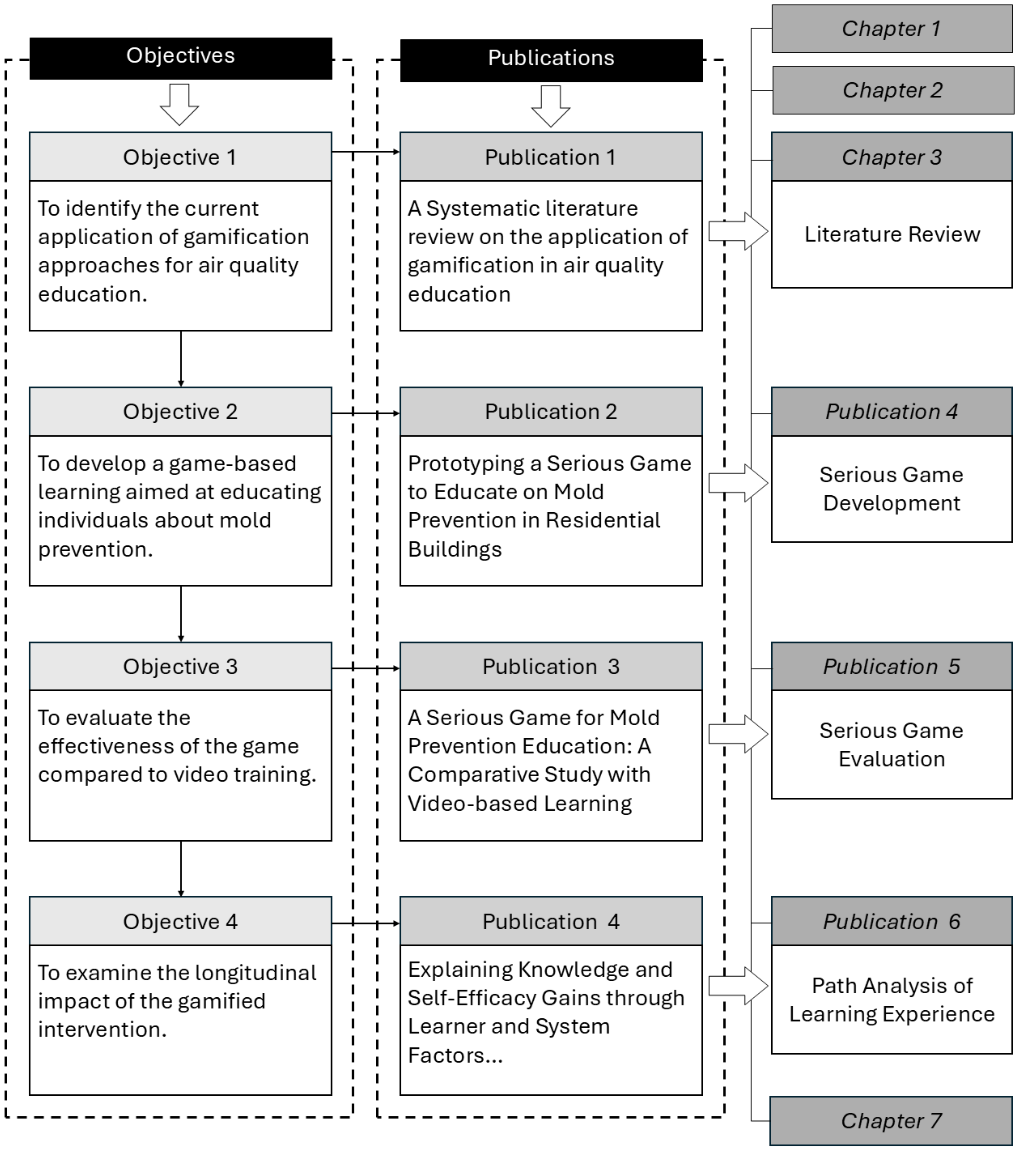

Figure 1.3: The thesis structure overview

Chapter 2

Research Methodology

This chapter outlines the methodological process and approaches adopted to achieve the research objectives of this study. Grounded in a pragmatic research philosophy, the study employs a mixed-methods approach that integrates both deductive and abductive reasoning. The research is structured around four interrelated objectives, each addressed through specific methods: a systematic literature review, serious game development, experimental evaluation, and path analysis using Structural Equation Modeling. The chapter details the research design, data collection instruments, participant recruitment, and ethical considerations. It also describes the verification processes, including expert interviews and home visits, to ensure the contextual relevance and educational accuracy of the game content. The methodology ensures both theoretical and practical applicability, enabling the development and evaluation of the serious game for mold prevention in New Zealand homes.

Chapter 2: Research Methodology

Research methodology refers to the systematic approach, techniques, and strategies used by researchers to conduct a study or investigation. Selecting an appropriate research methodology is essential for the effectiveness of any research project. The chosen methodology dictates the nature of the data acquisition, the methods employed for gathering information, and the subsequent analysis procedures (Elsevier, 2023). According to Dawson (2019), a research methodology is the primary principle that will guide your research. It becomes the general approach in conducting research on your topic and determines what research method you will use (Tiffin University, 2022). The following sections include the research methodology components. Notably, based on the research aims and objectives, the strategy includes both survey and experimental measurement.

2.1 Research Philosophy

Research philosophy refers to the set of beliefs, assumptions, and principles that guide a researcher's approach to conducting research (Onwuegbuzie et al., 2009). It provides the underlying framework for the researcher's worldview and influences their choice of research methods, techniques, and procedures. Research philosophy helps researchers make decisions about how they perceive reality, gather, and interpret data, and draw conclusions (Muis et al., 2006). Creswell and Creswell (2022) believe that there are four main research philosophies, such as post-positivism, constructivism, advocacy/participatory, and pragmatism. Each philosophy has its own perspective on the nature of reality, the role of the researcher, and the methods used to study phenomena. These philosophies shape the overall approach and methodology of the research study.

This study adopts Saunders' Research Onion framework (Saunders et al., 2023) to structure its methodological orientation. This model offers a layered approach to understanding research design, beginning with philosophical underpinnings and progressing through data collection techniques. Each layer reflects decisions made during the research process, ensuring methodological coherence and transparency.

Based on the nature of this study, pragmatism can be suitable for the aim of the present research. Pragmatism, as a philosophical approach, emphasizes practical outcomes and solutions to real-world problems (Kaushik & Walsh, 2019; Morgan, 2014).

This study adopts a pragmatic research philosophy, driven by the need to evaluate both the measurable learning outcomes of the serious game and the subjective user experience surrounding gameplay. The central goal of the research is not to test philosophical claims about reality, but to identify the most effective methods for answering the research questions and improving the educational intervention in practice.

Rather than beginning with a fixed methodological allegiance, methodological choices were made based on their usefulness in generating insight. For example, quantitative methods were used to measure knowledge scores, self-efficacy, motivation, task load, knowledge retention, and system usability. Qualitative feedback collected during prototype testing offered direct insight into how users interacted with the game and where improvements were required. This blending of methods reflects a pragmatic stance that prioritizes methodological utility over theoretical purity.

This philosophy also aligns with the iterative nature of the development process. Game mechanics, narrative elements, and feedback systems were refined based on user interaction and observed performance, supporting ongoing responsiveness to emerging insights. Methods were selected because they offered practical value at each stage: systematic synthesis of literature for conceptual grounding (Objective 1), user-informed design of the serious game (Objective 2), experimental comparison with traditional learning (Objective 3), and modeling of psychological mechanisms through SEM to reveal possible underlying causal relationships (Objective 4).

2.2 Research Approach

This study employed a multi-layered research approach, aligned with Saunders' Research Onion, which combines both deductive and abductive strategies to support the complex and iterative nature of game-based educational intervention design.

Deductive reasoning guided the formulation of hypotheses regarding expected improvements in learning outcomes associated with game-based instruction. For example, based on prior literature claiming that gamification enhances engagement and promotes knowledge retention, it was hypothesized that participants using the serious game would outperform those watching the instructional video in gaining knowledge and retention. This reasoning also shaped the statistical testing of model pathways in SEM, where theory-informed constructs (motivation → self-efficacy → knowledge acquisition) were quantitatively evaluated.

Inductive reasoning emerged during early user engagement and prototype development. Insights derived from expert interviews and home-visit investigations informed the alignment of the game's educational content with mold-prevention practices, ensuring that the educational elements were grounded in actual residential contexts. The design was adapted using insights from experts and real home observations, rather than being fixed entirely in advance.

Abductive reasoning facilitated the interpretation of unexpected or unclear findings during the study. When certain results did not align with initial theoretical expectations, abductive reasoning allowed for the consideration of possible explanations and refinement of interpretation of how motivation, task load, and learning factors influenced participant outcomes.

This hybrid logic of inquiry enabled the research to remain theoretically grounded while practically responsive. It reflects a pragmatic paradigm, where theory and empirical evidence inform each other continuously throughout the research process. This dual approach was essential in ensuring that the serious game was both educationally effective and user-centered, fulfilling the dual aims of academic rigor and real-world applicability.

2.3 Research Methods

This section outlines the research methods employed to achieve the study's objectives. Each research objective is aligned with a specific methodological framework to ensure that the evidence collected is valid, reliable, and suited to the corresponding research question. The methodological design integrates both quantitative and qualitative elements within a mixed-method paradigm, combining systematic literature review, serious game development, experimental evaluation, and path analysis. The research is structured around four interrelated objectives, each addressing a distinct stage of the study. To ensure methodological consistency, specific research methods were adopted to correspond with the analytical and developmental needs of each objective. Figure 2.1 illustrates an overview of the research methodology. Table 2.1 summarizes the process of the four interconnected studies.

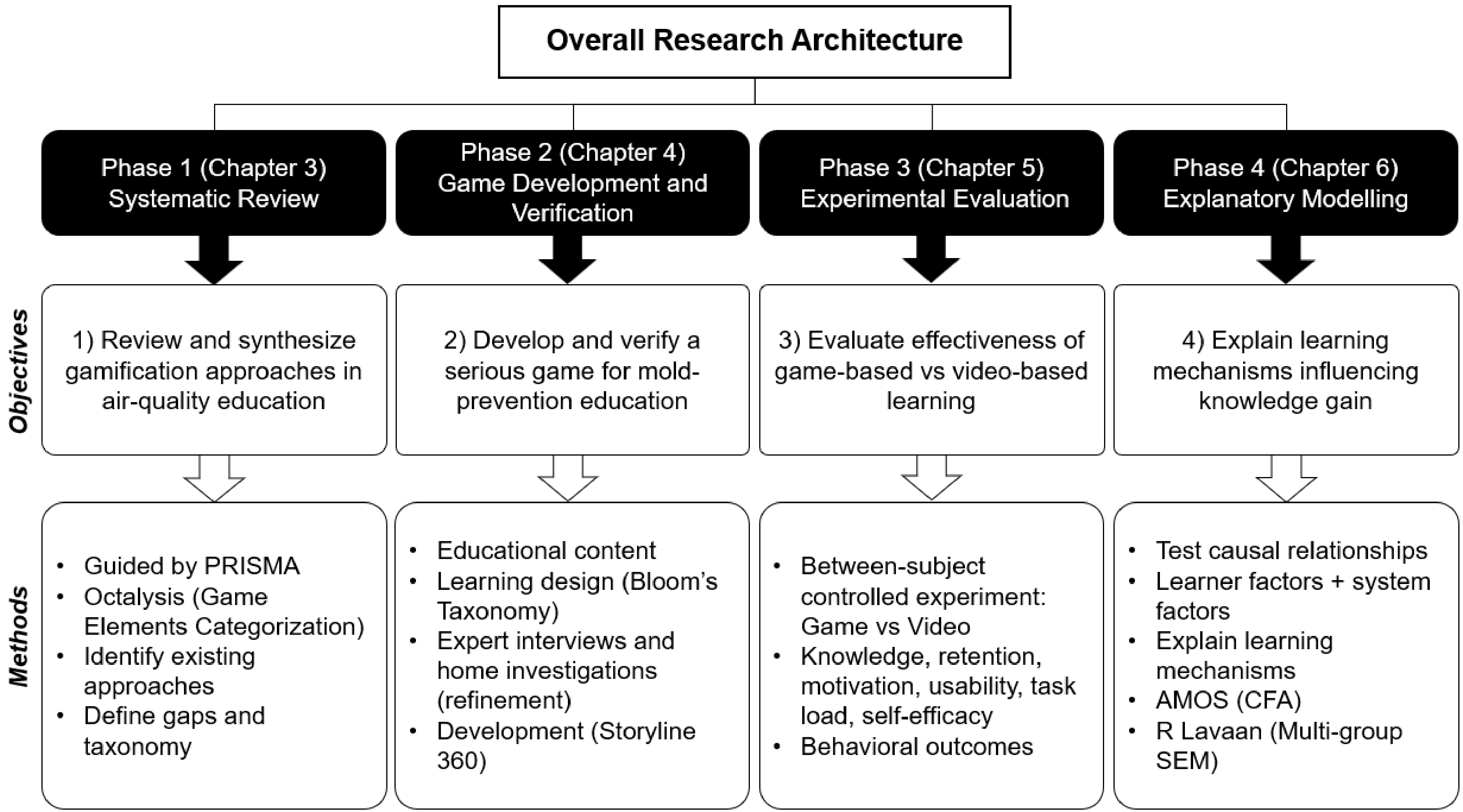

Figure 2.1: An overview of the research design and process

Table 2.1: Summary of the four interconnected studies

Phase	**Purpose**	**Methods**	**Sample**	**Analysis and Tools**
Phase 1	Identify research gaps in gamified IAQ education	Systematic Review (PRISMA)	19 published studies	Descriptive & narrative synthesis / Octalysis Framework
Phase 2	Develop and verify serious game prototype	Expert interviews; home visits; prototype development	12 experts; 6 homes	Thematic analysis; refinement / NVivo
Phase 3	Evaluate effectiveness of game vs video	Controlled experiment (pre, post, retention)	n = 120 (110 valid)	Non-parametric tests; effect sizes / SPSS
Phase 4	Explain mechanisms underlying learning outcomes	Structural equation modelling + CFA + path modelling)	n = 110	Model fit indices; bootstrapping / AMOS & R

Objective 1: To review the application of gamification in air quality education in Objective 1, a systematic literature review was used to identify existing research on the application of gamification for air quality education in the built environment. This method was selected to ensure a transparent, reproducible, and unbiased synthesis of evidence, allowing for the identification of trends, gaps, and methodological practices across the literature. The review followed the PRISMA guidelines, which provide a standardized framework for conducting and reporting systematic reviews. In line with the structured process proposed by Khan et al. (2003). The study involved four main steps: defining the research questions, identifying relevant works, summarizing the evidence, and interpreting the findings. This systematic process strengthened the reliability and consistency of the review outcomes.

A systematic search was conducted on October 17, 2024, across three major academic databases: Scopus, Web of Science, and IEEE Xplore. These databases were chosen for their extensive and multidisciplinary coverage. The keyword string used in the search was: *"gamif"* OR "serious gam*" OR "game-based" OR "interactive learning" AND "air quality"*. No restrictions were placed on publication date, document type, or language to ensure inclusiveness. The asterisk operator allowed for all possible variants of the keyword "game" to be captured. After removing sixteen duplicate entries, the screening process followed two stages: first, a title and abstract screening to ensure relevance, and second, a full-text screening to confirm that each selected study included gamification components, educational elements, and some form of empirical or prototype evaluation. To strengthen the search, backward and forward snowballing was conducted to identify both foundational and recent studies related to gamification and air quality. This process resulted in nineteen eligible studies published between 2009 and 2023.

Clear inclusion and exclusion criteria were defined to ensure methodological consistency. Studies were included if they were peer-reviewed journal articles, conference papers, or book chapters that explicitly focused on gamification or serious games for indoor or outdoor air quality education. Both digital and non-digital formats were considered. Studies were excluded if they were review papers, conceptual proposals without gamified elements, or publications unrelated to air quality (e.g., energy efficiency or comfort-only topics). Data extraction was performed using a structured coding framework aligned with the eight research questions. For each eligible study, information was gathered on the game's context, educational objectives, participant characteristics and sample sizes, game mechanics, delivery platforms, reported results, and underlying learning theories.

To classify and interpret the gamification components, the Octalysis Framework (Chou, 2015) was adopted as the analytical model. This framework divides gamified experiences into eight Core Drives of human motivation: Epic Meaning and Calling, Development and Accomplishment, Empowerment of Creativity and Feedback, Ownership and Possession, Social Influence and Relatedness, Scarcity and Impatience, Unpredictability and Curiosity, and Loss and Avoidance. Each study was coded according to these Core Drives and their corresponding game elements (e.g., points, leaderboards, avatars, and feedback systems). The Octalysis framework was used not as a design tool but as a diagnostic framework for systematically identifying and categorizing gamification strategies in the reviewed studies.

The synthesis process involved both descriptive and narrative analyses. Descriptive analysis summarized the publication trends, study contexts, and delivery technologies (e.g., mobile apps, AR, or computer-based tools), while the narrative synthesis compared results across studies to reveal recurring game mechanics, engagement outcomes, and theoretical gaps. The findings were visualized using figures and tables, including a Sankey diagram linking game elements with the Core Drives identified through Octalysis. To ensure reliability and validity, the review followed several strategies. These included adhering to the PRISMA protocol for transparency, using multiple databases to minimize publication bias, employing snowballing techniques for comprehensive coverage, and adopting a standardized coding scheme to maintain consistency across reviewers. Ethical approval was not required for this research, as it involved secondary data derived solely from previously published, peer-reviewed sources.

Objective 2: For Objective 2, the study began by developing educational content grounded in publicly available national sources, including New Zealand building codes, governmental regulations, and international publications related to mold prevention. These sources provided a foundation for identifying key learning objectives, which were structured using Bloom's Taxonomy (Krathwohl, 2002) to ensure a progressive learning experience. To refine and validate this educational content, the researchers conducted semi-structured interviews with twelve IAQ experts from diverse professional backgrounds, including building scientists, sustainability specialists, and housing assessors. The interviews were conducted via Microsoft Teams, recorded, and transcribed. The qualitative data were then analyzed using NVivo, a software tool for coding and thematic analysis. Experts provided feedback on terminology, environmental thresholds, and practical strategies, resulting in several refinements to the game design. In parallel, home-visit investigations were carried out in six houses in Auckland. These visits allowed us to observe and photograph real mold-prone areas, which were then compared with the expert feedback to ensure contextual accuracy and realism in the game design.

The serious game prototype was developed using Articulate Storyline 360, a tool that supports interactive and sequential learning experiences. The development process followed a waterfall model, progressing through phases of content creation, game mechanics design, prototyping, and verification. To evaluate the effectiveness of the game, a single-arm experimental design was implemented. Sixty participants from the general public in Auckland were recruited through convenience sampling, with 56 completing the study after attention checks. Participants completed a pre-test to assess baseline knowledge, engaged with the game, and then completed a post-test. Knowledge was measured across four domains: identifying mold-prone areas, understanding mold growth conditions, recognizing optimal temperature and humidity ranges, and recalling prevention strategies. Responses were manually scored, and statistical analysis was conducted using IBM SPSS Statistics Version 30. The Wilcoxon signed-rank test was used to analyze the difference between pre- and post-test scores. Additionally, Cohen's d was calculated to determine the effect size, which indicated a large effect and was used to quantify the magnitude of knowledge change resulting from the intervention.

Objective 3: For objective 3, the study utilized a controlled experimental design, including between-subject to evaluate the effectiveness of a game-based learning compared to a video-based learning method for educating the general public on mold prevention in residential buildings. The game was designed to be accessible across devices, smartphones, tablets, laptops, and PCs. Participants were recruited through a non-probabilistic convenience sampling strategy, with a total of 120 individuals from the general public. They were randomly assigned to either the game-based or video-based learning group, with 60 participants in each. A power analysis with a large effect size ($d = 0.8$), a significance level of $\alpha = 0.05$, a statistical power of $1 - \beta = 0.80$, and a two-tailed test to detect the mean difference between two independent groups was conducted using G*Power 3.1.9.7, indicating 26 participants as the required sample size for each group. Given that this study involved a four-week retention test, where sample sizes might drop for the retention test, a larger sample size of 60 participants for each group was selected. This sample size aligns with those reported in related studies in the field, such as Tarng et al. (2016) with n = 56, Zhang and Robb (2021) with n = 60, Paes et al. (2024) with n = 50, Feng et al. (2024) with n = 40, and Domgue K et al. (2025) with n = 60. Ten participants failed the attention check, resulting in 56 participants for the game group and 54 participants for the video group. Also, the number of participants completing the retention test dropped to 36 for the game group and 33 for the video group.

Participants were provided with an information sheet and asked to sign informed consent forms before participating. Each received an NZD $10 supermarket voucher as a token of appreciation. The experimental procedure consisted of three stages: before the learning experience (pre-test), immediately after the learning experience (post-test), and after four weeks (retention test). Both learning interventions contained identical content and visuals to ensure consistency. The video used the same narration and images as the game. Participants completed the pre-test, intervention, and post-test in a lab setting using laptops.

Data collection instruments included both qualitative and quantitative measures. Demographic data, including age, gender, housing type, and frequency of playing video games, were collected during the pre-test. Baseline knowledge was assessed using an open-ended questionnaire. Participants could earn up to 30 points in total, with specific scoring rubrics. For the post-test, intrinsic motivation was measured using a customized version of the Intrinsic Motivation Inventory (IMI), which included subscales for interest/enjoyment, perceived competence, and pressure/tension, each rated on a 7-point Likert scale. System usability was evaluated using the NASA Modified System Usability Scale (NMSUS), while task load was assessed using the NASA Task Load Index (TLX), which includes six dimensions rated on a 0–20 scale. Self-efficacy was measured using the General Self-Efficacy Scale (GSE), consisting of five items rated on a 7-point Likert scale. Behavioral change was assessed using a five-item questionnaire, also rated on a 7-point Likert scale.

For data analysis, the dataset was first screened for completeness, and responses failing an attention check were excluded, resulting in 110 valid participants (56 in the game group and 54 in the video group). Normality of the data was assessed using the Kolmogorov–Smirnov test and visual inspection, which indicated non-normal distributions. Consequently, non-parametric tests were used: Mann–Whitney U tests for between-group comparisons. Effect sizes were calculated using Cohen's d, with different formulas applied for between-group and within-group analyses. This comprehensive methodological approach ensured a robust evaluation of the educational effectiveness, usability, and behavioral impact of the serious game compared to traditional video-based learning.

Objective 4: To address Objective 4, the study used path analysis to investigate how learner-related factors (such as prior knowledge and self-efficacy) and system-related factors (including usability, task load, and intrinsic motivation) interact to influence learning outcomes in game-based and video-based learning experiences. For data analysis, the study used a multi-group Structural Equation Modeling (SEM) approach using the Lavaan package in R. Prior to SEM, the dataset was screened for multivariate outliers using Mahalanobis distance, resulting in the removal of four cases and a final sample of 106 participants. Composite scores for each latent construct were computed by averaging item responses, and Confirmatory Factor Analysis (CFA) was conducted using IBM SPSS AMOS v.29 to validate the measurement model. Model fit was evaluated using standard indices, including CFI, TLI, RMSEA, SRMR, and chi-square statistics. The structural model was then tested to examine the direct and indirect relationships among the variables, with bootstrapped confidence intervals (based on 2,000 resamples) used to assess the significance of the path coefficients. The SEM framework integrated both pre-test (knowledge and self-efficacy) and post-test measures (knowledge, self-efficacy, motivation, task load, and usability).

2.4 Ethics

This research involved human participants, so obtaining ethical approval was a critical part of the process to ensure all activities were conducted responsibly and aligned with university ethics standards. The project was reviewed and assessed as low risk. It included several components that required ethical consideration, including semi-structured interviews, home visits, and a controlled experimental study. To protect participants, clear information sheets were provided outlining their rights, including the option to withdraw at any time without any negative consequences.

Informed consent was obtained prior to participation, and care was taken to minimize any potential risks. These risks included possible discomfort with using unfamiliar technologies, concerns about privacy and data handling, or feelings of pressure to participate, especially for those involved in industry settings. To address these concerns, all participants received support throughout the study, and their data was anonymized and stored securely to ensure confidentiality.

Ethics approval was granted by the Massey University Human Ethics Committee under three separate low-risk applications. The first, approved on 19 August 2024 (Ref: 4000028748), covered the interviews. The second, approved on 2 December 2024 (Ref: 4000029998), addressed home visit procedures. The third, approved on 6 March 2025 (Ref: 4000030296), granted approval for the main experiment. Documentation related to these approvals is included in Appendix C.

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STATEMENT OF CONTRIBUTION DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Abdollah Baghaei Daemei
Name and title of main supervisor:	Dr Zhenan Feng
In which chapter is the manuscript/published work?	Chapter 3

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Abdollah Baghaei Daemei: Writing– review & editing, Writingoriginal draft, Visualization, Resources, Methodology, Investigation, Conceptualization. Ruggiero Lovreglio: Writing– review & editing, Supervision, Conceptualization. Zhenan Feng: Writing– review & editing, Supervision, Methodology, Conceptualization. Daniel Paes: Writing– review & editing, Supervision, Conceptualization. Clayton Miller: Writing– review & editing.

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Baghaei Daemei, A., Lovreglio, R., Feng, Z., Paes, D., & Miller, C. (2025). Gamification for air quality education: A systematic literature review. Building and Environment, 112526. https://doi.org/10.1016/j.buildenv.2025.112526

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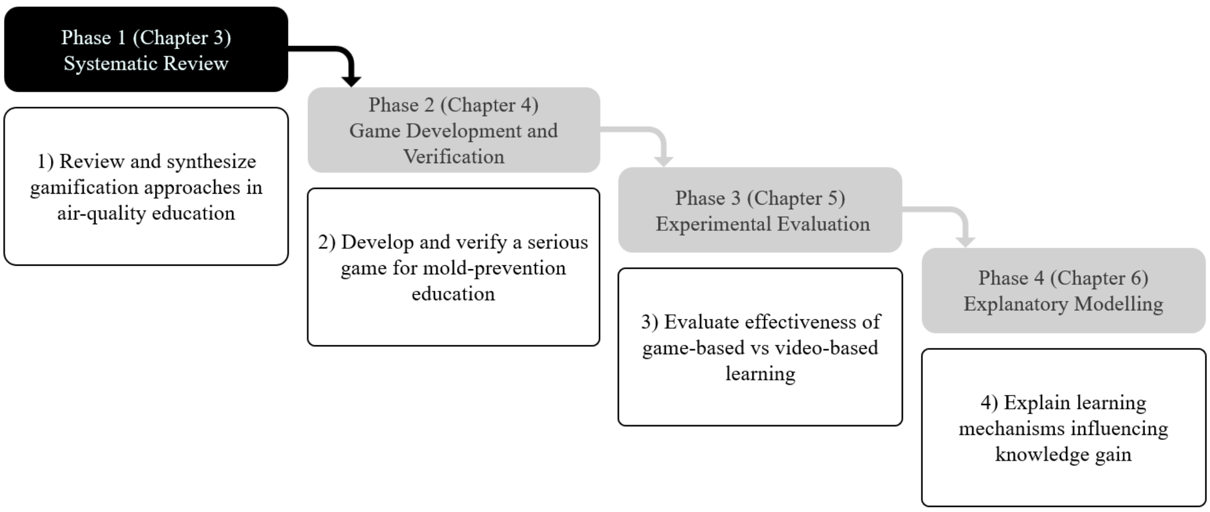
Chapter 3

Literature Review

This chapter is based on the following Journal article, which has been published in final form:

Baghaei Daemei, A., Lovreglio, R., Feng, Z., Paes, D., & Miller, C. (2025). Gamification for air quality education: A systematic literature review. Building and Environment, 112526. https://doi.org/10.1016/j.buildenv.2025.112526.

This chapter presents a systematic literature review aimed at examining the current state of research on gamification with a specific focus on air quality. Positioned as a foundational component of the thesis, this chapter investigates how serious games and gamified platforms have been designed, implemented, and evaluated in built environment contexts to inform and change user behavior. The review identifies gaps in how digital interventions leverage psychological, pedagogical, and motivational frameworks to enhance air quality awareness and behavioral change. The findings subsequently form the basis for the serious game development reported in Chapter 4.



Chapter 3: Literature Review

3.1 Introduction

In our rapidly evolving world, poor indoor and urban air quality and pollution have risen to the forefront of environmental concern, affecting the design of the future built environment (Liu et al., 2022; Moghadam et al., 2023). This nationwide issue poses significant threats to public health indoors and outdoors (Li et al., 2019). Being exposed to elevated air pollution levels can lead to various adverse health consequences, such as respiratory infections, heart problems, and lung cancer, which causes almost seven million deaths worldwide per annum (Lelieveld et al., 2015; Silva et al., 2017). The COVID-19 outbreak contributed to the importance of indoor air quality in buildings and its impact on occupants' health (Buonomano et al., 2023). High concentrations of CO_2 in indoor spaces can impact personal factors such as human productivity and increased tiredness levels (Korsavi et al., 2021; Satish et al., 2012). Low air quality and exposure to air pollutants can have health impacts in both the short and long term, with particularly severe consequences for individuals who are already unwell (Unni et al., 2022). Vulnerable groups, including children, pregnant women, the elderly, and those with limited financial resources, are at a heightened risk (WHO, 2019). Additionally, it irritates the nose, throat, eyes, and skin, causing headaches, dizziness, or nausea (Bernstein et al., 2008; Manisalidis et al., 2020a). This emphasizes the need for holistic global solutions to overcome such issues (Brunekreef & Holgate, 2002; Kampa & Castanas, 2008). The repercussions of air pollution extend beyond immediate discomfort. An increasing amount of evidence indicates that air pollution can also have detrimental effects on the brain (Blanco et al., 2024; B. Zhang et al., 2023).

According to a report published by Underwood (Underwood, 2017), dirty air causes cognitive ageing and potentially elevates the risk of Alzheimer's disease and other types of dementia. In another study, Wang (Wang et al., 2024) provided new evidence demonstrating the link between air pollution, stroke, and dementia. Thus, educating individuals about the sources and consequences of air pollution is critical, equipping them with educational content about air quality to the utmost (Aslam et al., 2023). Such knowledge can help people change their behavior, make informed decisions, and promote overall health and well-being (McCarron et al., 2023; Steinemann et al., 2017). The necessity to educate the public about the sources and consequences of air pollution is closely tied to the concept of Environmental Health Literacy (Raufman et al., 2020). As the National Institute of Environmental Health Sciences highlighted in 2014 (Lindsey et al., 2021) Environmental Health Literacy is an evolving concept integrating theories from risk communication, environmental health science, behavioral science, evaluation, communications, public health, and the social sciences (Kim et al., 2024).

One promising avenue for delivering engaging and effective air quality education is through gamification (Douglas & Brauer, 2021; Johnson et al., 2016). Gamification applies game elements and principles in non-game contexts (Kim et al., 2018; Long et al., 2023). Integrating educational content on air quality into interactive and immersive games can enhance people's awareness (De Jans et al., 2017). This approach utilizes the enjoyment and motivational aspects of games to encourage positive changes in behavior (Behl et al., 2024; Boso et al., 2020). Studies show people are more engaged and productive in gaming activities (Buckley & Doyle, 2016). Kim (2012) stated that games can boost people's performance in ways that real-world scenarios might not achieve. Similarly, many studies have reported positive educational outcomes in the gamification (Barna & Fodor, 2018; van Roy & Zaman, 2018; Yildirim, 2017). As such, gamification can play a crucial role in air quality education. It can help users understand how they can play a role in enhancing air quality and the impact of their decisions on other factors, such as thermal comfort and energy consumption.

Despite preliminary research on the topic of gamification for air quality education, the current understanding of utilizing gamification techniques to educate the public about air quality (indoors and outdoors) lacks a comprehensive overview. Although some papers exist on the topic, there has not been a systematic review that consolidates and analyzes the state-of-the-art approaches. Even though scattered research articles may touch upon aspects of gamification and air quality education, a comprehensive review is necessary to synthesize existing knowledge, identify trends, assess effectiveness, and uncover gaps in research. Such a review would provide valuable insights for researchers, policymakers, and practitioners seeking to leverage gamification as a tool for public education on air quality.

While evidence from other fields may suggest the potential benefits of gamification, particularly in engaging learners and promoting behavior change, no studies have directly compared gamification's impact to traditional methods regarding knowledge acquisition, retention, and behavioral changes specifically related to air quality education. For example, various studies have investigated the effectiveness of digital and innovative methods (i.e., gamification) in training, including for earthquake preparedness (Çoban & Göktaş, 2023; Feng et al., 2021; Mirsoleymani et al., 2022), safety training (Kazar & Comu, 2021; Lovreglio et al., 2021), construction sites (Lu et al.; Tagliabue et al., 2020), hazard detection (Cavalcanti et al., 2021; Mohd et al., 2019; Ren et al., 2022), risk management (Taillandier & Adam, 2018), and other general topics in the built environment (Ilbeigi et al., 2024; Lai et al., 2020; Villagrasa et al., 2014).

This study reviews the application of gamification in air quality education by identifying various delivery methods and game elements used for educational purposes. The term 'game element' is called 'game mechanics' or 'techniques.' In this study, the term game elements will be used. A systematic literature review was conducted to achieve this aim, assessing nineteen papers published between 2009 and 2023. This work involved analyzing the context and methods of gamification applications. The Octalysis framework was developed by (Chou, 2015) has been used to assess the gamification strategies adopted in these studies, marking this work the first instance of the Octalysis framework application in air quality educational research. Additionally, the research aimed to identify specific game elements that effectively stimulate individual motivation and engagement.

This review study represents a new milestone in air quality education research, contributing new insights into how gamification and game elements have been adopted for air quality education and new ideas on how gamification can be applied in the future. Although various studies have assessed the effectiveness of serious games and gamification in the built environment, the current state of gamification in air quality education remains largely unknown. More importantly, there is no existing taxonomy for gamification or serious games specifically related to air quality education. This work proposes the first such taxonomy, providing a structured framework for the development and analysis of gamified applications and serious games in this field.

3.2 Background

This section provides a brief background about gamification and game elements. Additionally, the types of games are classified. Subsequently, the differences between serious and non-serious games are distinguished, along with categorizations into non-digital and digital games, and a summary of immersive and non-immersive games is provided. Furthermore, critical issues of IAQ and OAP are explored, emphasizing their significant impact on public health and the environment. Throughout this work, referencing 'air quality' encompasses both IAQ and OAP unless explicitly specified otherwise.

3.2.1 Gamification

Gamification integrates gaming elements, principles, and mechanics into non-game contexts to engage and motivate individuals (Oliveira et al., 2023). It involves applying elements or game elements commonly found in games, such as competition, points, rewards, badges, challenges, and interactive storytelling, to activities that typically do not involve gameplay (Zichermann & Cunningham, 2011). Gamification enhances user engagement, increases motivation, and drives desired behaviors. Gamification makes tasks more enjoyable, boosts participation, and achieves specific objectives (Alsawaier, 2018). It uses the psychological aspects that make games compelling, such as the desire for achievement, competition, and the enjoyment of challenges (Buckley & Doyle, 2016). Game elements refer to the individual components or features that make up a game, including badges, avatars, points, etc. These elements contribute to the overall gaming experience, providing interactive and visual aspects that engage players (Sharma et al., 2024).

Game designers can use various game elements to create challenges, objectives, and the overall structure of a game. These elements work together to create a unique and engaging gameplay experience. Game designers must carefully balance and iterate these elements to ensure the gaming experience is enjoyable, challenging, and aligned with the intended player experience (Mekler et al., 2017). In general, games are classified into serious games and non-serious games. Serious games are primarily designed for education, training, simulation, or informational purposes rather than pure entertainment. Serious games often use gaming elements to make learning or training more engaging and effective (Susi et al., 2007). The main objective of serious games is to impart knowledge, teach specific skills, or simulate real-world scenarios (Abt, 1987; Ritterfeld et al., 2009). In contrast, non-serious games, also known as entertainment or recreational games, are designed primarily for entertainment purposes (Yates, 2021). These games focus on providing an enjoyable experience without specifically emphasizing educational or training objectives (McDaniel et al., 2010).

Serious games can also be categorized into non-digital and digital games. Non-digital games are traditional games that do not involve electronic or digital technology. These games are played using physical components, such as cards, boards, dice, or other tangible items, and they do not rely on computerized or electronic interfaces (Naderi & Moafian, 2023; Naik, 2014). Digital games can be further divided into immersive and non-immersive. Immersive games are designed to deeply engage players in a virtual environment, creating a sense of presence and involvement, aiming to make players feel like they are part of the game world, blurring the line between the virtual and real (Jennett et al., 2008). Virtual reality and Augmented Reality (AR) technologies are commonly used to create immersive gaming experiences (Brown & Cairns, 2004). Non-immersive games may not employ advanced technologies to create a deeply engaging virtual environment. These games still provide entertainment but may not focus on creating a sense of high immersion (Porter III et al., 2018). In non-immersive games, the player's awareness of the real-world environment may be more pronounced, and the gameplay may not strive to create a fully immersive experience (Pallavicini et al., 2019).

3.2.2 Air Quality and Education

Generally, air quality refers to the condition of the air within our surroundings, describing how polluted the environment is (Lewis et al., 2023). It is a multidimensional concept that assesses the cleanliness of the air people breathe and its impact on their health, the environment, and overall well-being (Picciano et al., 2023). Monitoring air quality indoors and outdoors involves evaluating the concentration of pollutants such as carbon dioxide, carbon monoxide, nitrogen dioxide, particulate matter, ozone, volatile organic compounds, etc. On the one hand, the goal is to maintain air quality within acceptable standards, as indicated by the Air Quality Index (Boso et al., 2020), to safeguard human health and the ecosystem (Akimoto, 2003). Also, raising public awareness should be considered to avoid the threat of toxic air.

Educating individuals about air quality is paramount due to its significant and far-reaching implications on public health and the environment (Marcotte, 2017). Also, they can actively participate in efforts to control and manage air pollution (Auerbach & Flieger, 1967). Many people are unaware of the invisible threats in the air they breathe, and raising awareness is crucial for making informed decisions and adapting behavior (Barbosa et al., 2017). If people become more aware of the importance of air pollution, it is more likely to prompt positive changes in both individual behavior and public policies (Kelly & Fussell, 2015). This increased awareness has the potential to drive actions to mitigate pollution, resulting in a cleaner environment and a healthier population (Arcury, 1990; Wang et al., 2016). Therefore, boosting education and training and increasing public awareness can lead the public to achieve goals related to environmental pollution (Manisalidis et al., 2020a).

Moreover, well-informed individuals are more likely to advocate for policies and practices contributing to cleaner air. This collective effort on a global scale can lead to reduced health risks, including lower rates of respiratory conditions such as asthma, improved overall well-being, and a healthier future for communities worldwide (Moreira et al., 2022). To this end, a practical educational approach to air quality is needed. An innovative approach gaining momentum is the incorporation of gamification into air quality education. Gamification transforms learning about air quality into an engaging and interactive experience by applying game elements and offering various features such as real-time data collection (Polychronidou et al., 2019). Through gamified applications and platforms, individuals can participate in challenges, quizzes, and simulations that simulate real-world scenarios related to air quality.

To date, a comprehensive exploration of the air quality educational applications of gamification in the context of the built environment is lacking in existing literature. This work aims to fill this research gap by providing a systematic literature review to explore existing gamification applications in air quality education.

3.3 Materials and Methods

This section outlines the methods employed in this work. In this study, a systematic literature review is used to identify relevant articles in the literature. This systematic approach allows researchers to rigorously identify, select, and synthesize relevant studies from various sources, ensuring a thorough and unbiased review of the existing literature (Tranfield et al., 2003). As such, this study utilized the step-by-step approach provided by Khan (Khan et al., 2003) to identify the eligible articles. This approach is designed to assess the relevance of identified work with research questions and reduce the number of papers to analyze. The steps used in this review are:

i. Defining research questions.
ii. Identifying the relevant work.
iii. Summarizing the evidence.
iv. Interpreting the findings.

3.3.1 Defining research questions

This research aims to provide insight into gamification applications oriented toward air quality. The following research questions (Q1 to Q8) were framed to seek the diverse aspects of gamification in air quality education. These research questions are inspired by a general classification of serious games developed by (Breuer & Bente, 2010). Further, the questions align with the previous systematic review conducted by (Scorgie et al., 2024), which used a similar approach. The research questions are presented as follows:

Q1: What was the primary context of the game?

Q2: What was the learning objective of the game?

Q3: What was the profile of the trainees, and what was the sample size?

Q4: What game elements were applied?

Q5: What types of delivery methods and applications were used?

Q6: What were the reported results?

Q7: What were the challenges of the delivery method and applications?

Q8: What psychological and learning theories or models were employed in the design of gamified air quality applications?

3.3.2 Identifying the relevant works

This study followed the PRISMA Statement to identify relevant articles (Figure 3.1). Relevant articles were retrieved from multiple databases, including Scopus, Web of Science (WOS), and IEEE Xplore. These databases were selected as the preferred database, as they have more global content than other providers while maintaining a selective approach (Elsevier, 2022; IEEE, 2023; Martín-Martín et al., 2021; Teles et al., 2020). This exploration was conducted on the 17th of October 2024 using the keyword string: gamif* OR "serious gam*" OR "game-based" OR "interactive learning" AND "air quality". No further filters of the database have been allocated in the search process (e.g., language and subject area). The '*' (asterisk) operator was used in the keyword to include all terms relating to gamification, such as gamify, gamifying, gameful, gamification, and gaming. After removing 16 duplicates from the three databases, an initial screening was implemented. After that, a secondary screening was conducted involving reading the full text to assess the eligibility of the studies.

The secondary screening concluded 12 eligible studies. After that, backward and forward snowballing were applied to these eligible articles. Backward snowballing consisted of tracing the references cited in foundational research papers, allowing us to explore the historical context of the topic and identify additional studies that significantly contributed to the field (Wohlin, 2014). Furthermore, forward snowballing was utilized to identify more recent studies that cited pivotal research papers (Wohlin et al., 2022). Another seven eligible studies were discovered through snowballing. Consequently, 19 eligible articles were included in this systematic literature review (Bosello et al., 2020; Campana & Xavier Dominguez, 2020; Carducci et al., 2016; Delmas & Kohli, 2020; J. Fernandes et al., 2023; Grossman et al., 2017; Kim et al., 2021; Kim & Sohanchyk, 2022; S. Kim et al., 2022; Leonardi et al., 2014; Ling et al., 2021; Mahajan et al., 2020; Niemeyer et al., 2009; Pokric et al., 2015; Relvas, 2021; Shabanabegum et al., 2021; Teles et al., 2020; Thomson et al., 2017; Varnavsky, 2020). Table 3.1: Eligibility criteria for the screening stages for selecting literature studies. Further, Appendix A provides a summary of the eligibility articles.

Table 3.1: Eligibility criteria for the screening stages

Stages	Criteria	Decision
Searching	Peer-reviewed studies such as journal articles, conference papers, and book chapters.	Inclusion
	When the specified keywords are present either in the entirety or at least within the paper's title, keywords, or abstract.	Inclusion
	In case of any duplication among the identified studies.	Exclusion
	Studies that are books, review papers, and metadata.	Exclusion
Title and abstract screening	Studies present sufficient information on the gamification of either indoor or outdoor air quality education.	Inclusion
	Studies that analyzed or tested any education methods, including digital (e.g. mobile apps or video games) and non-digital (e.g. classroom-based activities or board games).	Inclusion
	The main focus was not on air quality education (e.g., energy efficiency, thermal comfort, etc.).	Exclusion
Full-text screening	Studies that only propose the use of gamification without any experimental testing.	Exclusion
	Studies that do not incorporate gamification elements in any form (e.g., points, rewards, challenges, or interactive play) as part of their methods.	Exclusion
	The studies have no information regarding the learners or testing subjects (characteristics and sample size).	Exclusion

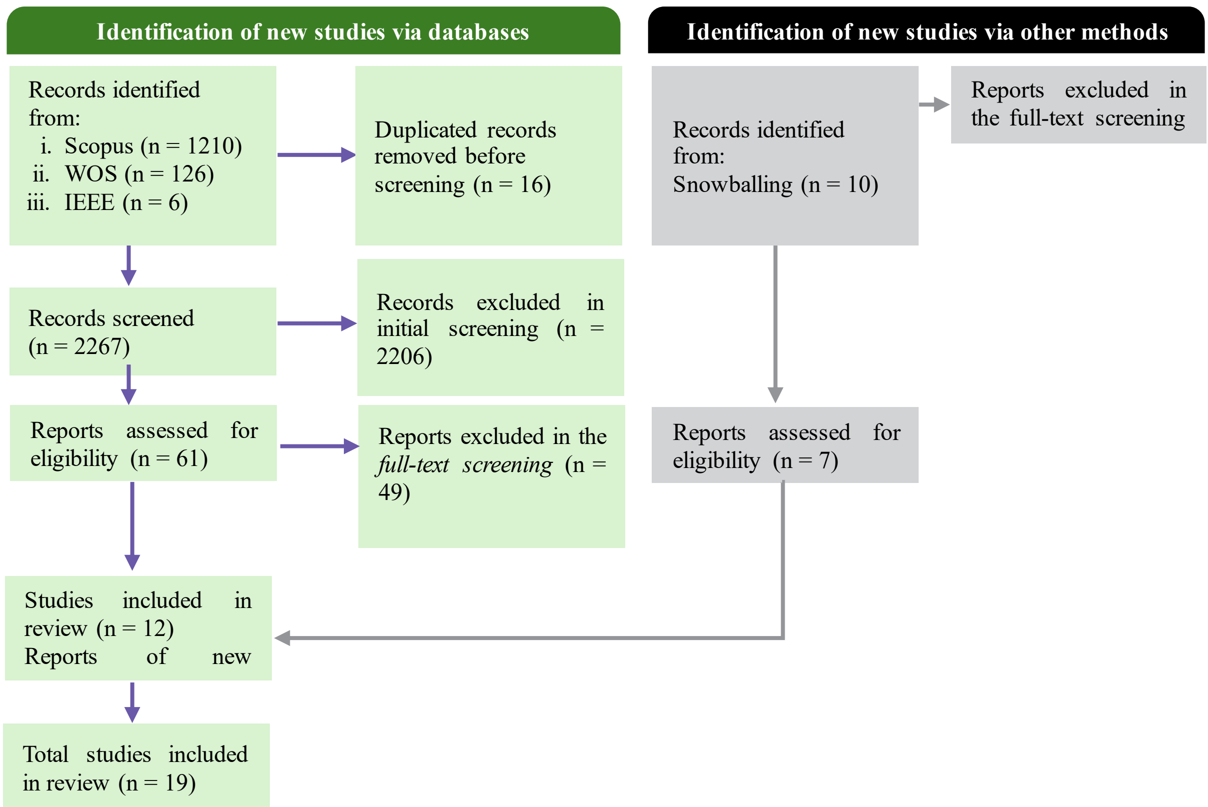


Figure 3.1: PRISMA flow diagram and the process of identifying the relevant works

3.3.3 Analysis Approach

One of our research questions (Q4) aims to assess the game elements adopted in the proposed air quality applications. To achieve this, we utilized the Octalysis framework, a well-established Gamification Design Framework developed by Chou (2015, p. 23). The Octalysis framework breaks down into eight Core Drives (CDs), represented in an octagon shape as shown in Figure 3.2 (hence the name "Octalysis"). Each CD also incorporates various game elements (as they can be seen in the corners of the Octalysis). These elements are the individual components or features within a game that contribute to the overall gaming experience (Rabin, 2009). For instance, points are a game element of CD 2. These CDs are the fundamental psychological motivations that drive individuals to engage in a particular activity or game.

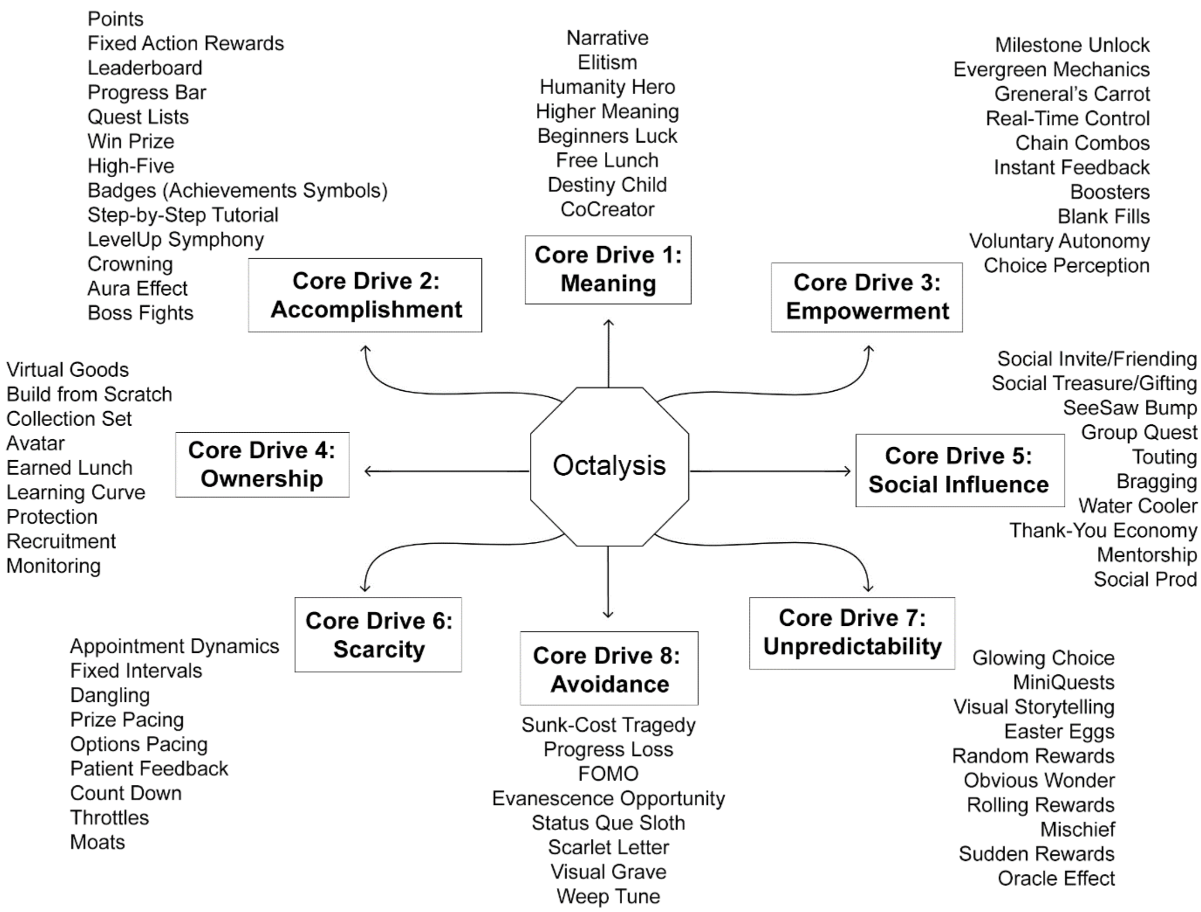
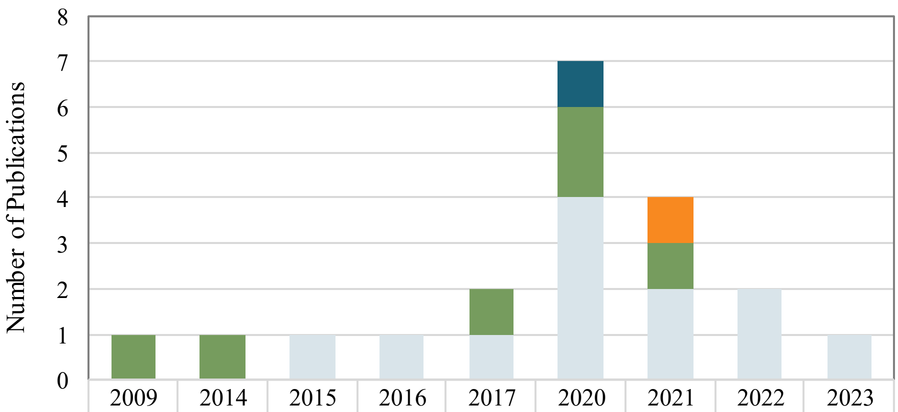


Figure 3.2: Gamification Design Framework, Octalysis, modified from

The Octalysis framework has been widely used in various fields, including marketing, education, and product design, to enhance user engagement and drive desired behaviors (Chen et al., 2023; Karać & Stabauer, 2017). As such, it represents a suitable tool for analyzing the gamification solution adopted in the selected papers for air quality education. Rather than using Octalysis to design game elements directly, we employed the Octalysis framework as a structured analytical model to systematically identify, categorize, and understand the game elements present in prior studies to respond to Q4.

3.4 Results

In this systematic literature review, a total of nineteen papers published between 2009 and 2023 were identified, comprising eleven journal articles, six conference papers, one book chapter, and one master's thesis. Figure 3.3 illustrates the number of publications and types of scholarly outputs per annum. The Figure shows a substantial increase in the number of applications in 2020 and 2021. This trend likely corresponds to the rise in research and publications during the COVID-19 pandemic, as the global situation heightened interest and urgency in health-related topics, including air quality education through gamification (Aviv-Reuven & Rosenfeld, 2021; Raynaud et al., 2021).



	2009	2014	2015	2016	2017	2020	2021	2022	2023
Thesis (1)							1		
Book Chapters (1)						1			
Conference Papers (5)	1	1			1	2	1		
Journal Articles (12)			1	1	1	4	2	2	1

Figure 3.3: Summary of the eligible articles' source output

3.4.1 Primary contexts of the games

This section explores the potential information concerning the first research question in this study, focusing on the primary contexts of the games discussed in the literature. The primary focus of the games revolved around diverse facets of air pollution, focusing on IAQ, OAP, and both. The findings show that three types of built environments have been investigated, including classrooms (one paper), residential buildings (seven papers), and general environments (eleven papers). The general environment implies that the study did not mention any specific case study, space, or building typology. Further, most studies used real-time data collection, integrating with the application which can collect various environmental parameters, namely temperature, CO_2, VOCs (Volatile Organic Compounds), CO, air pressure, PM10, PM2.5, $N0_2$, formaldehyde, UVI (Ultraviolet Index), O_3 (ozone), PM1.0, PM4.0, PM1, smoke, benzene, sulfide, and alcohol. Detailed information on the built environment context and the IAQ and OAP parameters are presented in Table 3.2.

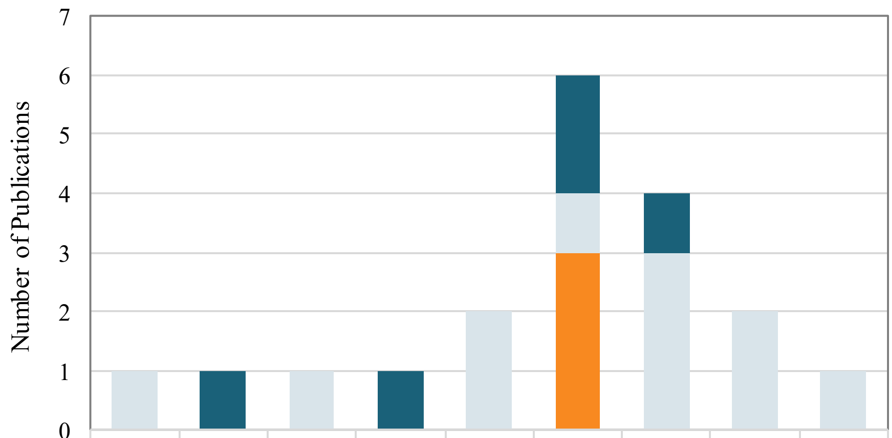
Table 3.2: Details of the main context of the games

Publications	Indoor/Outdoor	Built Environment	Real-time IAQ and OAP elements
(Niemeyer et al., 2009)	Indoor	Classroom	Temperature, CO_2, and VOCs*
(Leonardi et al., 2014)	Both	General	CO, air pressure, temperature
(Pokric et al., 2015)	Indoor	General	Temperature, air pressure, humidity
(Carducci et al., 2016)	Both	General	N/A
(Thomson et al., 2017)	Indoor	Residential	PM10, PM2.5, VOCs, N02, CO
(Grossman et al., 2017)	Indoor	Residential	N/A
(Bosello et al., 2020)	Outdoor	General	Temperature, humidity, PM1.0, PM2.5, PM10, formaldehyde, UVI
(Teles et al., 2020)	Outdoor	General- Lisbon's Downtown (virtual environment replication)	NO_2, O_3, PM2.5, PM10
(Campana & Xavier Dominguez, 2020)	Indoor	General	PM1.0, PM2.5, PM4.0, PM10
(Varnavsky, 2020)	Outdoor	General	N/A
(Delmas & Kohli, 2020)	Both	General	N/A
(Mahajan et al., 2020)	Both	General	PM1, PM2.5, PM10
(Ling et al., 2021)	Indoor	General	CO_2, NOX, NH_3, smoke, benzene, sulfide, alcohol

(Relvas, 2021)	N/A	General-Virtual environment replication	N/A
(Shabanabegum et al., 2021)	Indoor	Residential	PM2.5, CO, CO_2, TVOC, NO_2
(Kim et al., 2021)	Indoor	Residential	PM2.5, CO_2, NO_2
(Kim & Sohanchyk, 2022)	Indoor	Residential	PM2.5, CO, CO_2, TVOC, NO_2
(S. Kim et al., 2022)	Indoor	Residential	PM2.5, CO, CO_2, TVOC, NO_2
(J. Fernandes et al., 2023)	Indoor	Residential	CO, NO_2, PM1, PM2.5, PM10

* This paper goes beyond measuring air quality parameters, including light and noise.

Figure 3.4 provides further details about the relationship between primary contexts and the number of publications per annum. Most of the articles investigated IAQ as the leading environmental context.

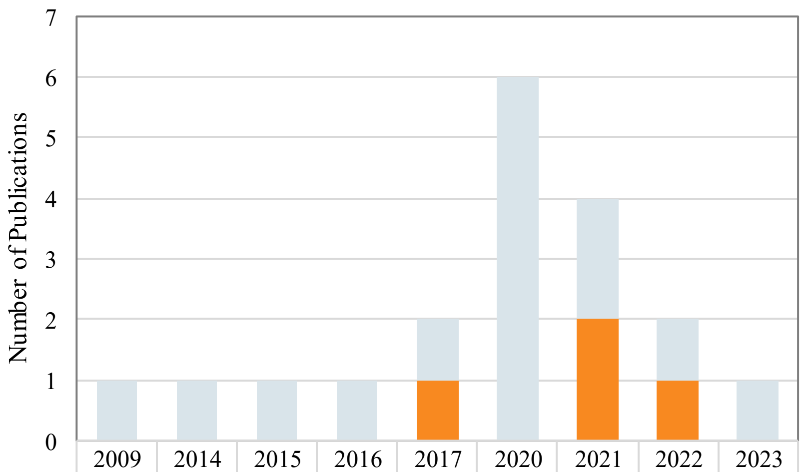


	2009	2014	2015	2016	2017	2020	2021	2022	2023
Both (5)		1		1		2	1		
Indoor (11)	1		1		2	1	3	2	1
Outdoor (3)						3			

Figure 3.4: Summary of the primary contexts of the eligible articles

3.4.2 Learning objective of the games

This section addresses the study's second research question regarding the primary learning objectives of the games, which are categorized into two main groups: asthma management (26%, four studies) and awareness and perception (74%, fifteen studies). Figure 3.5 illustrates the relationship between these key contexts and the number of publications per year. The asthma management objective focuses on helping users control and alleviate asthma symptoms by fostering daily asthma management behaviors. This is achieved by highlighting the link between air quality and respiratory health (Grossman et al., 2017; S. Kim et al., 2022). Key strategies include supporting users with IAQ monitoring (Shabanabegum et al., 2021) and providing reminders to ensure adherence to prescribed asthma management measures (Kim et al., 2021). The objective of awareness and perception aims to enhance users' understanding of air pollution and its impacts. This involves raising awareness of pollutant exposure, promoting knowledge of associated health effects, and emphasizing the significance of IAQ. The objectives also seek to foster social responsibility, encourage behavioral changes, and promote the adoption of protective measures. Collectively, these initiatives aim to create well-informed and engaged users who are better equipped to address the challenges posed by air pollution.



	2009	2014	2015	2016	2017	2020	2021	2022	2023
Raising Awareness (15)	1	1	1	1	1	6	2	1	1
Asthma Management (4)					1		2	1	

Figure 3.5: Summary of the primary objectives of the eligible articles

3.4.3 Profile of the trainees and the sample size

This section provides possible results to answer question 3 on the profile of the trainees. The gamification applications identified in this review were developed and tested for three generic groups of trainees, namely i) adults aged from eighteen to seventy-five, ii) teenagers aged from thirteen to seventeen, and iii) children below twelve years old. Figure 3.6 represents the sample size distribution of the trainees involved in testing the gamification solutions in the selected works. Based on the findings, adults include professional employees and bachelor students, while teenagers comprise individuals from high school and senior high school. Children predominantly consist of elementary school students. Additional details about trainees' profiles can be found in Figure 3.7.

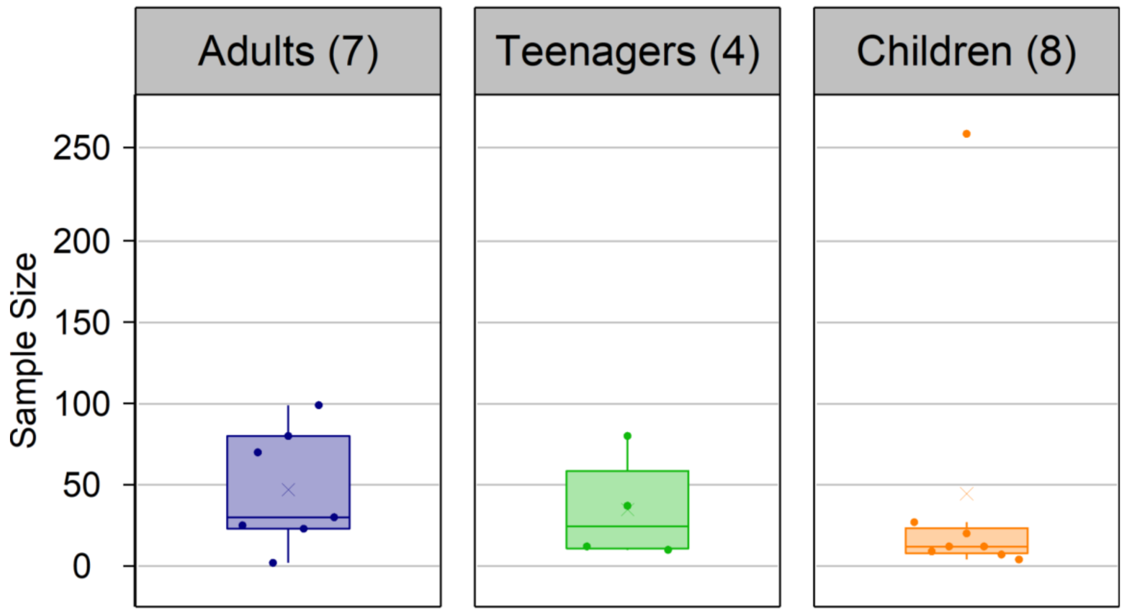
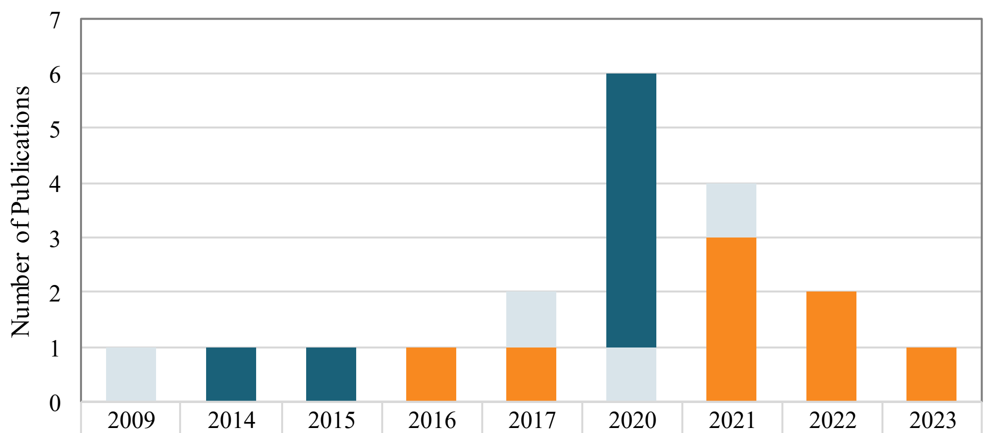


Figure 3.6: Sample size distribution of the selected works



	2009	2014	2015	2016	2017	2020	2021	2022	2023
Adults (7)		1	1			5			
Teenagers (4)	1				1	1	1		
Children (8)				1	1		3	2	1

Figure 3.7. Trainees' profile

3.4.3.1 The applied game elements

According to the fourth research question in this work, this section delves into the applied game mechanics in the literature. In the analysis of eligible articles, 16 distinct game elements were identified. Each element is associated with reference game elements within different CDs (Table 4). Labels A to P were assigned to correlate with each game element to facilitate reference and categorization. For instance, Pokric et al. (2015) employed three game elements, namely 'scores, points, and awards', 'choosing an avatar', and 'leaderboard'. Each game element is associated with reference game elements and labels: E – 'points', K – 'avatar', and F – 'leaderboard'. In some cases, the authors mentioned the game elements not associated with the reference game elements. Consequently, they were revealed as Not Available (N/A). Relvas (2021) used a game element entitled ‘Main Character Explains to the Player and Dialogue’. In this case, this game element conveys two meanings. Therefore, two reference game elements were considered for it, which are ‘Narratives’ and ‘Virtual Storytelling’. Varnavsky (2020) did not clarify the game elements they utilized in their game. Hence, it was coded as Not Clarified (N/C). In Table 3.3, only the game elements found within the eligible papers were listed, not the complete group of game elements mentioned in the Gamification Design Framework (see Figure 3.2 for further details about the game elements). Appendix B presents a definition of each game element and provides quotes from the original reference.

Table 3.3: The game elements translator

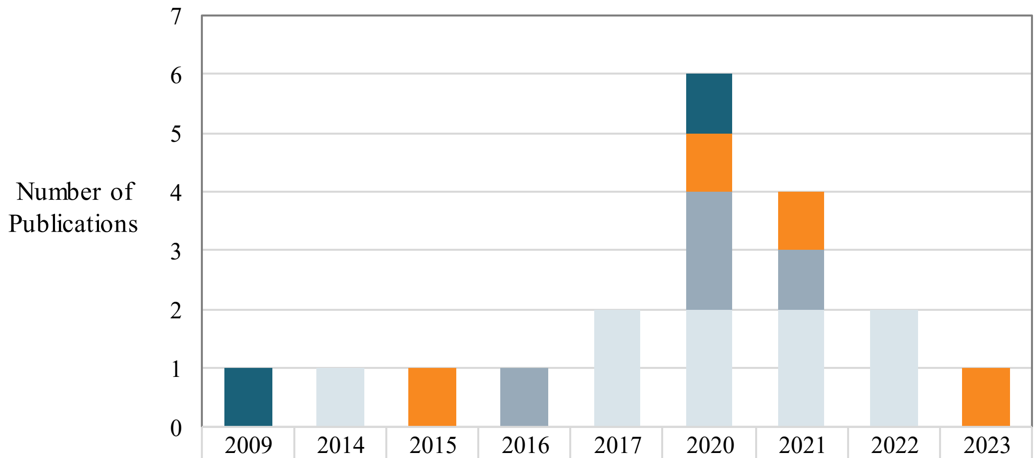
Sources	Retrieved Game Elements	IDs		Reference Game Elements, developed by Chou (2015)															
				CD1	CD2							CD3			CD4	CD5		CD7	CD8
				A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
				Narratives	LevelUp	Quest Lists	Step-by-Step Tutorial	Points	Leaderboard	Progress Bar	Win Prize	Instant Feedback	Choice Perception	Boosters	Avatar	Group Quest	Social Invite/Friending	Visual Storytelling	Progress Loss
[89]	Various Roles and Teams	3	M																
	Social Interactions		N																
	Difference in-Game Activities		N/C																
[90]	Real-time Feedback	1	H																
[91]	Scores, Points and Awards	3	E																
	Choosing an Avatar		K																
	Leaderboard		F																
[92]	Storyboard	5	A																
	Choose a Player (Boy or Girl)		L																
	Multiple Levels		B																
	Score		E																
	Score Reduction		P																
[93]	Reminders	9	N/C																
	Feedback		H																
	Personalized Character, picks a name and avatar		K																
	Rewards and Prize		E																
	Task Completion and Daily Missions		C																
	Answering Questions		N/C																
	Secret Code		J																
	Space Locker		N/C																
	Take Photos for Postcards		N/C																
[94]	Customizable Avatar	11	K																

	Scorecard		E
	Monetary Award		G
	Reminder		N/C
	Milestone		N/C
	Objective		C
	Dialog Box		N/C
	Rules		N/C
	Punishment		P
	View Their Counterparts' Score		N/C
	Immediate Feedback		H
	Motivations		N/C
[95]	Achievements, Level and Experience	3	B
	Registration and Login		N/C
	Sitting on a bus (passenger)		N/C
	Driving different buses		I
	Tasks		C
[86]	Tutorials and help	6	D
	Two driving modes		N/C
	Teleport option		N/C
	Filter Options		N/C
	Information Button		N/C
[96]	Particles Scale and Risk Buttons	5	N/C
	Rural		N/C
	Pause and Play Option		N/C
[97]	N/C	-	N/C
[106]	Tomorrow's Forecast	2	N/C
	Prize		G
	Storytelling Sessions		O
[98]	Play with Joystick-based Console	3	N/C
	Collaboration		M
[99]	Integrating a Mini Game	1	N/C
	Main Character Explains to the Player and Dialogue		A/O
[100]	Different non-Player Characters	6	N/C
	Different Game Features		N/C
	Player's Objectives		C

	Game tutorial		D																
[101]	Chatbot	2	N/C																
	List of Action Items		I																
[102]	Pick Different Emojis and Personalized Characters	4	K																
	Track the History of Monitored Information		L																
	Informational content		D																
	Chatbot to Answer Questions		H																
[103]	Suggests Proper Actions	2	N/C																
	Animated Narrative Cat		A																
[104]	Chatbot	2	H																
	List of Recommendation Actions		I																
[105]	Collaboration	8	M																
	Tutorial		D																
	Objectives		C																
	Content		N/C																
	Non-Playable Character (Guide/Hint)		A																
	Scores		E																
	Feedback		H																
	Users Can Choose the Role		I																
Frequency of occurrences of Game elements				4	2	5	4	5	1	1	2	6	4	1	5	3	1	2	2
Frequency of occurrences of Core Drives (CDs)				4	20							11			5	4		2	2

3.4.4 Types of delivery methods and applications

This section provides answers for question 5 of this work on the delivery methods. Various methods and applications have been utilized to gamify air quality education. This review shows that most studies applied digital games. These games were mainly available on three main technologies, such as smartphones or tablets, as evidenced by the selected works. Also, laptops, PCs, and AR have been used to deliver the games. Also, two studies were categorized as 'Others'. Figure 3.8 illustrates these methods by year.



	2009	2014	2015	2016	2017	2020	2021	2022	2023
Others (2)	1					1			
Augmented Reality (4)			1			1	1		1
Laptops or PCs (4)				1		2	1		
Smartphones or Tablets (9)		1			2	2	2	2	

Figure 3.8. Illustration of the types of delivery methods and applications

The studies identified 2D and 3D games, played on smartphones/tablets or PCs/laptops. Some games were further integrated with activities, such as real-time air quality monitoring devices, and interactive quizzes and offline questionnaires combined with air quality sensors. Other methods, like cartoons and video games, were also used. Another activity was the bicycle crowdsensing system, where users contribute data on cycling routes and environmental factors via mobile devices. AR integration appeared in four studies. For example, AR was used to place 3D objects in real-time video, enhancing immersion, and Unity with Vuforia was employed to create an AR app featuring a virtual character with sensor data represented by health and hunger states. Additionally, AR was used to visualize environmental data for education, and in one study, children interacted with virtual and real-world elements to make invisible information accessible. However, none of the studies utilized head-mounted displays or immersive virtual reality solutions. Table 3.4 represents the usage of each tool or activity in the related game/environment type.

Table 3.4: Categorization of game types, tool, and associated activities

Tool/Activity	2D Environment	3D Environment	AR Integration	Crowdsensing
Interactive Quizzes	✓			
Real-time Air Quality	✓	✓	✓	
Unity/Vuforia (AR)			✓	
Sensor Integration			✓	
Data Collection via Mobile (bicycle)				✓

3.4.5 Reported findings

Based on question six in this study, the reported findings were classified into three groups: i) user engagement and feedback, ii) educational impact and awareness, and iii) perception and willingness. The reviewed studies present a positive outlook on user engagement within various applications. Niemeyer et al. (2009) and Bosello et al. (2020) reported overall positive feedback, underscoring high user engagement. Thomson et al. (2017) found that users, particularly children, experienced improved engagement and considered the game fun and helpful. Teles et al. (2020) observed high usage success rates, satisfactory task completion times, and positive user experiences. Campana and Xavier Dominguez (2020) confirmed using smartphone environmental applications could increase trainees' social responsibility. They also concluded that the game increase curiosity and users' engagement. Varnavsky (2020) noted that smartphone environmental applications contributed to heightened social responsibility, reflecting an active user participation trend. However, S. Kim et al. (2022) observed that while the graphical interface of their game received positive initial impressions, trainees reduced app use due to a perceived lack of interactivity and fun, highlighting areas for improvement. J. Fernandes et al. (2023) reported a significant improvement in knowledge (about 50%) and positive assessments of satisfaction, usability, and opinions. Mahajan et al. (2020) noted overall positive user feedback regarding the tools, highlighting raised awareness and engaging user experiences.

Regarding educational impact and awareness, Leonardi et al. (2014) reported an increase in curiosity, leading to heightened motivation and awareness among citizens, indicating a positive educational impact. Pokric et al. (2015) stated that trainees found the game entertaining and the content provided was educational. Carducci et al. (2016) found that video games designed for children were useful, simple, and fun. In this study, trainees demonstrated noteworthy enhancements in learning outcomes by engaging in the videogame-based learning activity, including leaflets and storyboards. Statistical analysis revealed a significant knowledge increase among individual responses ($p < .05$). Delmas and Kohli (2020) observed that positive user experience increased users' perception of air pollution.

Regarding perception and willingness, the reviewed studies also revealed varying aspects of trainees' perception and improvement needs in the context of air quality applications. Ling et al. (2021) reported that 60% of trainees expressed willingness to use the application, indicating a positive overall perception and readiness to engage. Shabanabegum et al. (2021) identified limited knowledge among children regarding IAP and its impact on asthma, suggesting the imperative for educational improvement. Kim and Sohanchyk (2022) noted positive initial interaction and increased parental involvement, signifying active parental and community engagement. Lastly, Relvas (2021) reported a significant improvement in children's perception after the post-assessment, indicating positive changes in understanding. These studies underscore the effectiveness of innovative applications and tools in fostering air quality awareness, education, and engagement.

3.4.6 Challenge of the delivery method or application

Question seven of this work sought any challenge to the applications reported in the literature. Some papers mentioned that they faced some challenges. For example, Pokric et al. (2015) reported encountering issues and highlighted the need for additional tutorials based on user feedback. Teles et al. (2020) criticized the application for lacking a rich narrative and having a poorly designed interface. Thomson et al. (2017) faced challenges due to the use of low-cost tethered devices, specifically impacting certain gameplay features. They used the Dylos air quality monitor, which relies on a wall outlet for power and a tethered 9-pin serial to a full USB connection to the tablet. Grossman et al. (2017) encountered design limitations, including issues with the positioning and visibility of the flashing light indicator due to the opacity of the plastic shell of the dose counter. The dose counter, integrated with the game, had some issues, including a lack of sturdiness and functional limitations. Communication errors between the dose counter and the app related to rewards cause user frustration and mistrust. Relvas (2021) reported occasional bugs, particularly in pause mode, displaying unpredictable behavior such as unresponsiveness or needing closure. Although infrequent during testing, these issues could potentially lead to trainee frustration. J. Fernandes et al. (2023) documented those trainees accepted occasional tracking failures of markers (box and ring) as part of the game's challenges.

Through trial and error, trainees developed strategies such as bringing the marker closer to the camera and maintaining parallel alignment with the image plane. The rest of the studies provided no information regarding the challenges they faced while using the application or the games.

3.4.7 Psychological and Learning Theories

This section also provides the results to answer question eight of this study. Based on the findings, only a few psychological and learning theories or models have been employed to gamify air quality education. Niemeyer et al. (2009) utilized John Dewey's theory, emphasizing the integration of play and work in the curriculum. John Dewey's theory is known as progressive education, experiential learning, and problem-solving. This theory values the social aspect of learning, fosters democratic values, and views education as a lifelong, continuous process (Gajic, 2024). Grossman et al. (2017) employed Captology and the Elaboration Likelihood Model (ELM) to enhance user engagement through a persuasion approach, offering a framework of social influence. This theory suggests that there are two routes to persuasion: the central route, where people carefully consider information and arguments, and the peripheral route, where persuasion relies on factors such as the attractiveness or credibility of the source rather than the content of the message (Petty & Cacioppo, 1986). Also, Delmas and Kohli (2020) focused on the Theory of Planned Behavior and the Theory of Issue Engagement, which show that having the intention to perform an action increases the likelihood of actually carrying out that action (Ajzen, 1991).

3.5 Discussion

The analysis of these selected papers was guided by the eight questions listed in Section 3.1. This study provides a further comprehensive understanding of the existing applications of gamification for air quality education. Based on the findings, the primary contexts explored in the eligible papers are IAQ, OAP, and both. In some cases, they just focus on the general environment. The main built environment/building typology is residential, which is the most common context. One study considered classrooms to assess the application of gamification. In addition, a study replicated Lisbon's Downtown as a virtual environment, and a study generally simulated a virtual environment to educate individuals about air pollution.

Regarding the learning objectives, the studies worked on educating the public about the impact of air pollution to enhance individuals' awareness of general pollutant exposure. These objectives extend further to educating the public about the health effects of air pollution and policies and fostering knowledge about air quality and healthy lifestyles. Additionally, the goals include improving children's understanding of asthma outcomes and promoting the routine habit of asthma control through education on the importance of air quality. The results of the eligible studies show that nine main game elements have been utilized for asthma management, including quest lists, points, win prizes, instant feedback, avatar, progress loss, choice perception, step-by-step tutorial, and progress bar (see Figure 3.9). Alternatively, Al-Rayes et al. (2022), who systematically reviewed the application of gamification in healthcare, highlighted that points, leaderboards, levels, feedback, and challenges are the predominant gaming elements utilized in gamified healthcare applications.

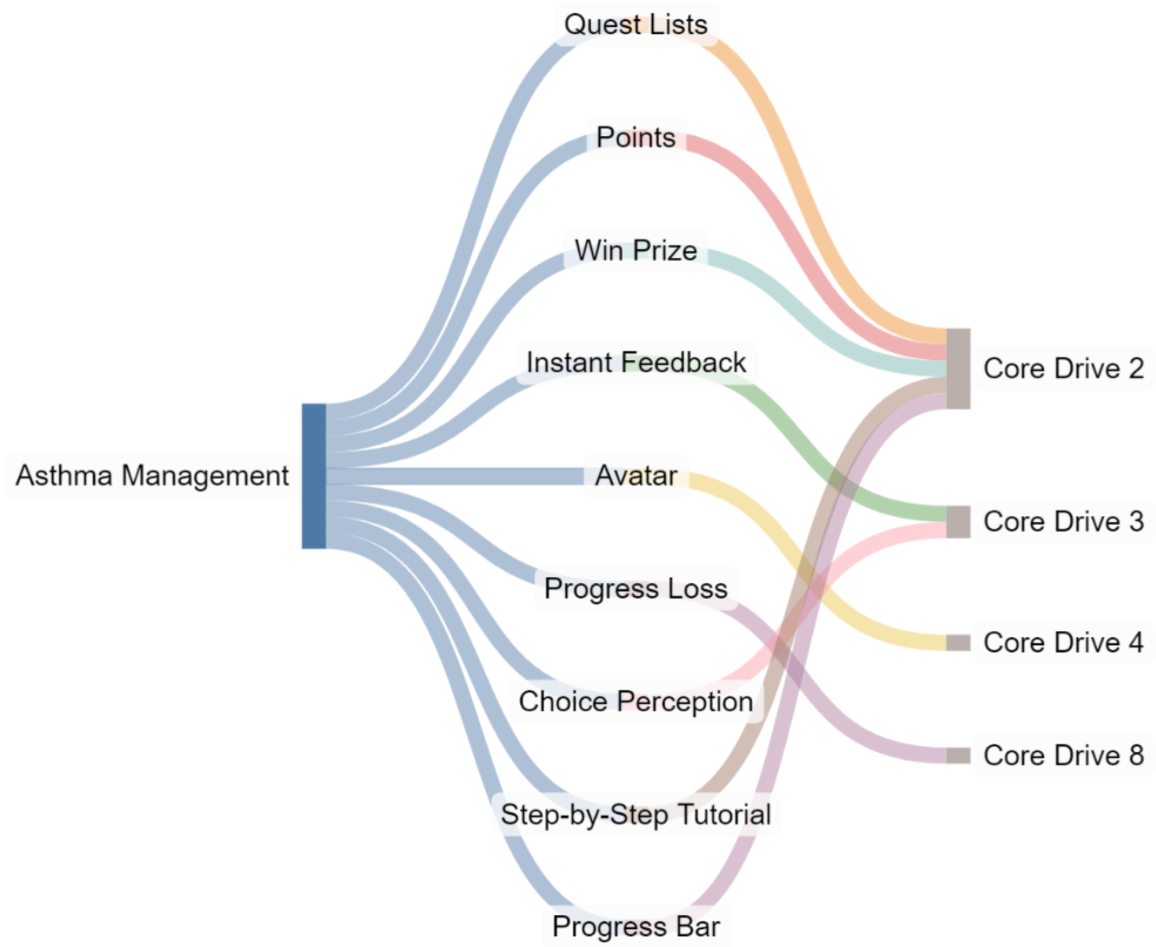


Figure 3.9: Sankey diagram depicting the relationship between game elements

In this review, the most common game elements delivered by the application of gamification were also identified. In general, a total of sixteen game elements within the eligible articles were identified and associated with the reference game elements. As a result, forty-nine game elements (including the sum of all game elements mentioned in the same way in all the articles) have been linked to the reference game elements. CD2 (Development & Accomplishment) and CD3 (Empowerment of Creativity & Feedback) were the CDs most used by applying nineteen and eleven game elements, respectively. In CD2, 'Quest Lists' (5), 'Step-by-Step Tutorial' (4), and 'Points' (5), and in CD3, 'Instant Feedback' (6) were the most used game elements (see Table 4). Figures 10 and 11 provide some information about the frequency of studies using CDs with primary context and trainees' profiles. These charts illustrate that each primary context and each group of trainees are linked with which CDs and highlight the overlap between the variables with CDs. More importantly, they show which CDs have been utilized more and which ones have not. Each parameter is presented in a separate chart due to insufficient or weak data for some parameters. Subsequently, these charts were consolidated into a single chart to enhance clarity.

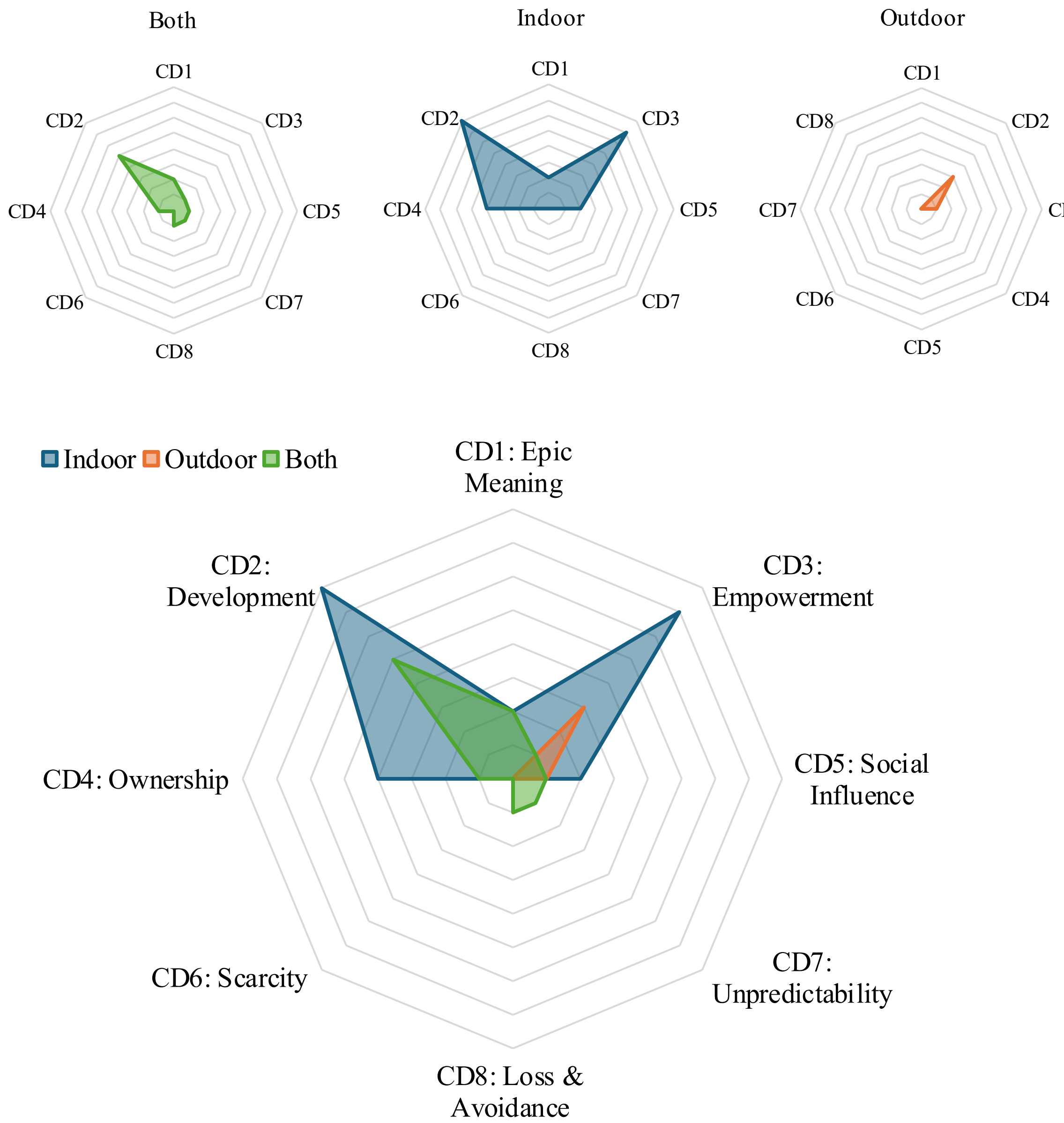


Figure 3.10: The frequency of Core Drives and primary contexts

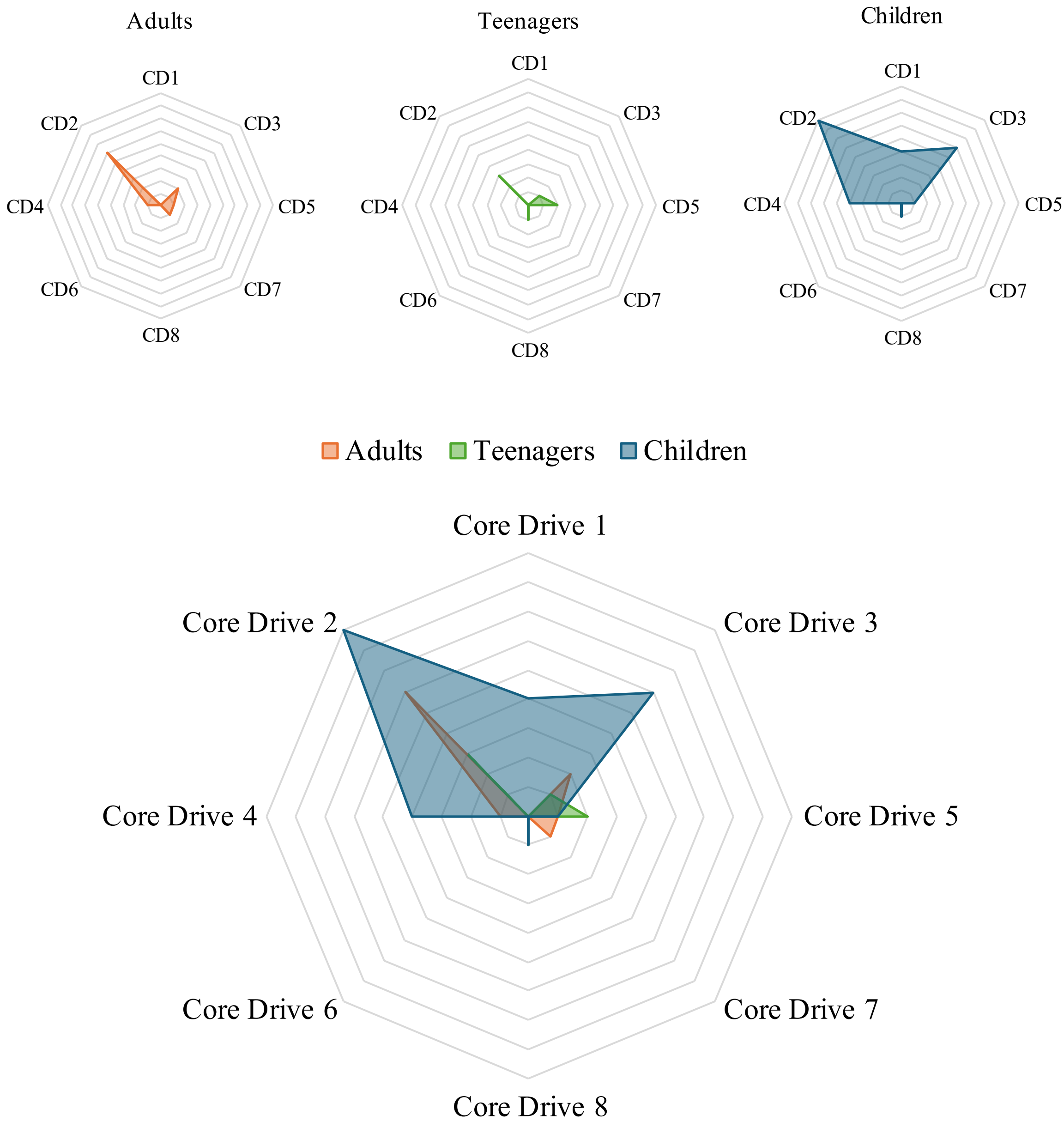


Figure 3.11: The frequency of Core Drives and trainees

The findings indicate that laptops or PCs were the primary delivery methods in four studies, while smartphones or tablets were used in 15 (see Fig. 8). These devices were often integrated with real-time data collection via sensors or crowdsensing through bicycles. Some studies reported positive feedback, improving trainees' awareness and engagement (Bosello et al., 2020; Leonardi et al., 2014; Niemeyer et al., 2009). Others highlighted that their games were entertaining, fun, and easy to use (Pokric et al., 2015; Thomson et al., 2017). Specifically, Carducci et al. (2016) found that 60% of children learned something from the game, with a 1.40% knowledge improvement post-assessment. Another study noted 60% of trainees expressed willingness to use the application (Ling et al., 2021).

Users consistently reported positive engagement with environmental applications, with confirmed usability and feasibility sparking curiosity and generating positive feedback. Smartphone apps showed potential to enhance social responsibility and understanding of air pollution. Post-assessments revealed significant improvements in children's perceptions and increased parental involvement. However, trainees initially found the graphical interface helpful for identifying asthma triggers, but reduced app use due to perceived lack of interactivity (S. Kim et al., 2022). J. Fernandes et al. (2023) showed a 50% improvement in knowledge, with satisfaction and usability assessed through questionnaires.

Overall, the studies emphasize the effectiveness of the applications in raising air quality awareness, with high user engagement and positive feedback. The educational impact was evident in increased curiosity and improved knowledge. However, few studies directly compared delivery methods or applications. J. Fernandes et al. (2023) found 85.2% of trainees preferred using real objects, while 14.8% preferred paper cards. Moreover, only a limited number of studies in air quality gamification have incorporated psychological theories (Delmas & Kohli, 2020; Grossman et al., 2017; Mahajan et al., 2020; Niemeyer et al., 2009), which are crucial for guiding intervention design and understanding behavioral change. While many reviews use meta-analysis to quantitatively assess research, this study faces limitations due to the lack of suitable quantitative data, restricting robust statistical analysis and the depth of insights.

3.5.1 Proposed taxonomy for air quality-related serious games

This work applied three approaches as foundations for proposing the taxonomy for air-quality related serious games/gamification, including the SDT (Gagné & Deci, 2005), the Octalysis framework (Chou, 2015), and the general taxonomy for serious games proposed by Breuer and Bente (2010). To ensure a systematic and rigorous categorization of findings, the proposed taxonomy is grounded in these established theoretical frameworks. The SDT provides insights into intrinsic and extrinsic motivation, which are essential to drive user engagement. In turn, the Octalysis framework offers a detailed breakdown of the Core Drives behind gamification, facilitating effective design strategies for behavioral change. Breuer and Bente’s taxonomy was chosen because of its impact on the field. It provides a suitable starting point for a taxonomy within the field of air quality education. The proposed taxonomy is presented in Figure 12.

While developing this taxonomy, the goal was to expand upon the original taxonomy proposed by Breuer and Bente (2010) to include items related to air-quality gamification based on the findings of this review. The proposed taxonomy is divided into seven classifications: platform, subject matter, learning goals, target audience, interaction mode, controls/interface, and motivation drives. It should be noted that these classifications correspond to each research question addressed in this study. Also, each classification within the taxonomy is accompanied by illustrative examples, all of which are achieved as a result of this study. However, these examples should not constrain or limit future research to only these instances in the future use of this taxonomy to classify papers or to develop new gamification solutions. Ultimately, this taxonomy is intended to provide a foundational framework and inspire innovative approaches in the development of serious games and gamified applications within the air quality education field.

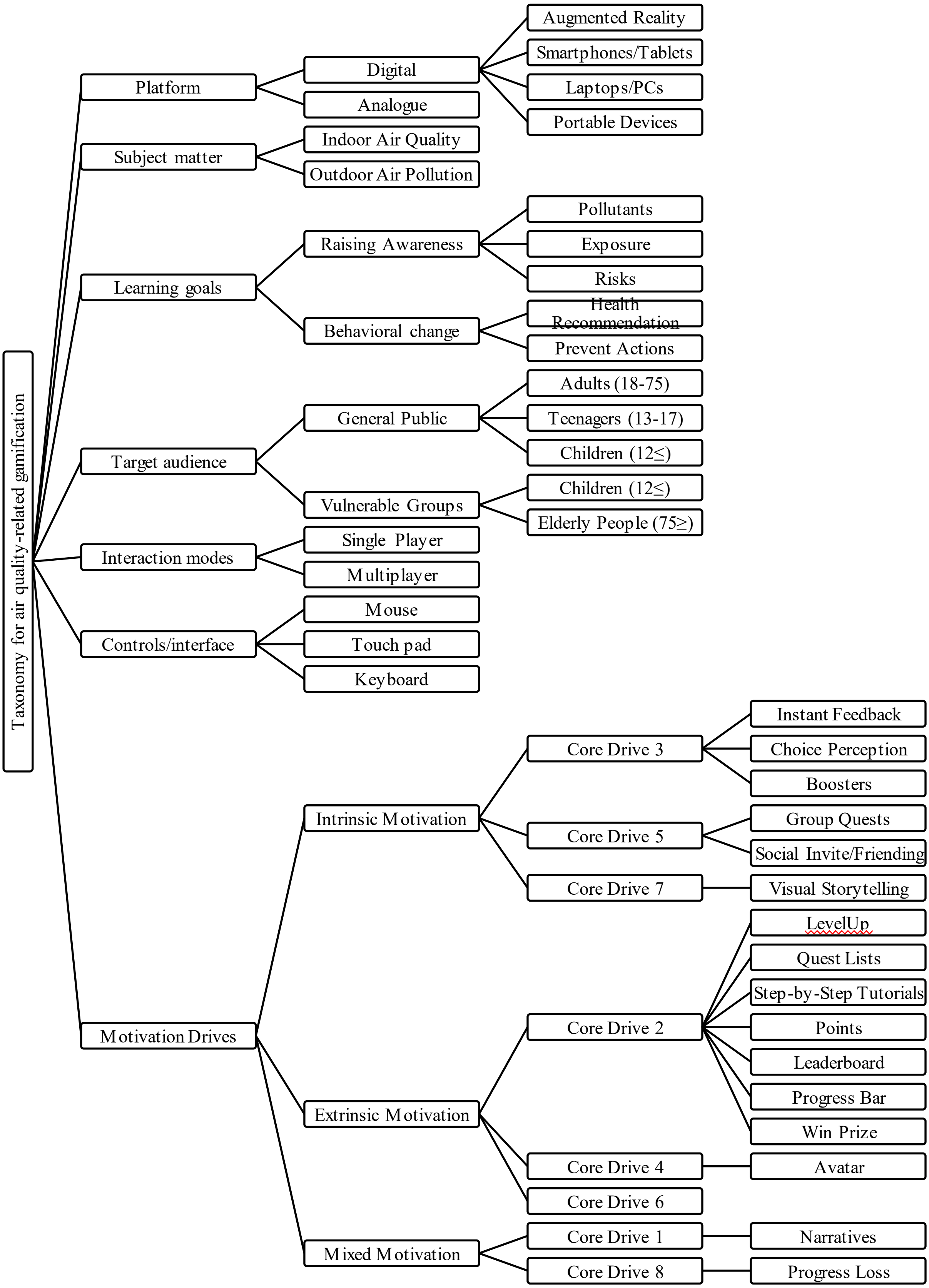


Figure 3.12: Taxonomy and classification for air quality-related gamification

This study aligns with two Sustainable Development Goals, including #3 (Good Health and Well-being) and #11 (Sustainable Cities and Communities). By addressing respiratory issues (e.g., asthma) caused by air pollution, this research contributes to reducing hospitalizations and premature deaths from IAP. It is also addressed as this review explores the educational potential of gamification and serious games to deliver educational content to individuals in improving indoor environments. Ultimately, this work supports the creation of more sustainable and resilient cities.

The practical implications of this research span several domains. For academia, this research offers the foundation for future studies on gamification in air quality education. It introduces a taxonomy based on established theories, offering a systematic way to design, evaluate, and classify gamified applications. This taxonomy will guide researchers in creating innovative gamified solutions and foster further academic exploration in air quality education. We also identified key game elements, delivery methods, and learning objectives for educational applications. This research offers guidance for policymakers to integrate gamified strategies into public health and urban planning, promoting behavioral change and sustainable practices in communities. Also, the proposed roadmap (Fig. 13) offers guidelines for practical implementations of new technologies integrated with the applications.

3.5.2 Research Gaps and Future Directions

This section provides research gaps. First, the studies covered different types of built environments; however, other types of built environments, such as office buildings or public spaces (e.g., restaurants, libraries, etc.), have not been investigated (see Appendix A). One plausible explanation for this gap may stem from the complexity of controlling IAQ in specific scenarios, such as office buildings or libraries. Notably, the eligible studies focused solely on the health impact of air quality. For example, none of the studies specifically addressed knowledge retention in the context of air quality gamification. Effective knowledge retention in air quality gamification is paramount for ensuring a lasting impact on users, facilitating long-term behavior change, and creating informed decision-making (Madani et al., 2017). Additionally, IAQ relates to the productivity and cognitive performance (X. Zhang et al., 2023), sleep quality (Strøm-Tejsen et al., 2016), human thermal comfort (Ma et al., 2021), and some aspects of environmental quality control, such as mold assessment (Qiao et al., 2024).

In the following, evidence of behavioral impact was found in only one study (Delmas & Kohli, 2020), highlighting the necessity for further investigation into this crucial aspect. Many studies within the eligible studies did not conduct tests on their games with substantial sample sizes. Out of the examined papers, four studies assessed their games with fewer than ten trainees ($n \leq 10$), while nine studies extended their testing to up to thirty trainees ($n \leq 30$). Consequently, it can be inferred that most of these studies relied on relatively small sample sizes for testing their applications. Current literature indicates a limited adoption of AR integration in gamified approaches, with no studies utilizing virtual reality headsets in game design. Furthermore, the majority of games are predominantly designed in 2D. Future research could explore innovative avenues by investigating the untapped potential of AR and VR technologies in gamification. Moreover, it is noteworthy that none of the studies incorporated simulations alongside the application of gamification. This limitation can be overcome in the future using various simulation-based scenarios that specifically address the importance of architectural strategies. i.e., windows and wind flow within buildings are used to control air pollution as well as mitigate energy consumption (Buonomano et al., 2023).

In addition, there is a lack of comparisons among different types of games, including traditional and innovative approaches (digital and non-digital), for the future direction. The effectiveness of these methods was not systematically assessed. Engaging a wider audience, especially in regions where technology is not as advanced, presents a significant challenge for air quality education. In future research, it will be important to include both quantitative and qualitative analyses to assess how well these tools help users acquire and retain knowledge and whether they lead to lasting behavior changes. A comparison of different types of games (traditional and digital) would also be valuable in understanding which methods work best for a better learning outcome. Engaging a wider audience, especially in regions where technology is not as advanced, presents a significant challenge for air quality education. Moreover, research connected to emerging technologies, such as AI and IoT-based environmental monitoring, is currently missing. Future studies should explore how these technologies can complement or enhance gamification tools. Figure 13 illustrates a proposed research roadmap.

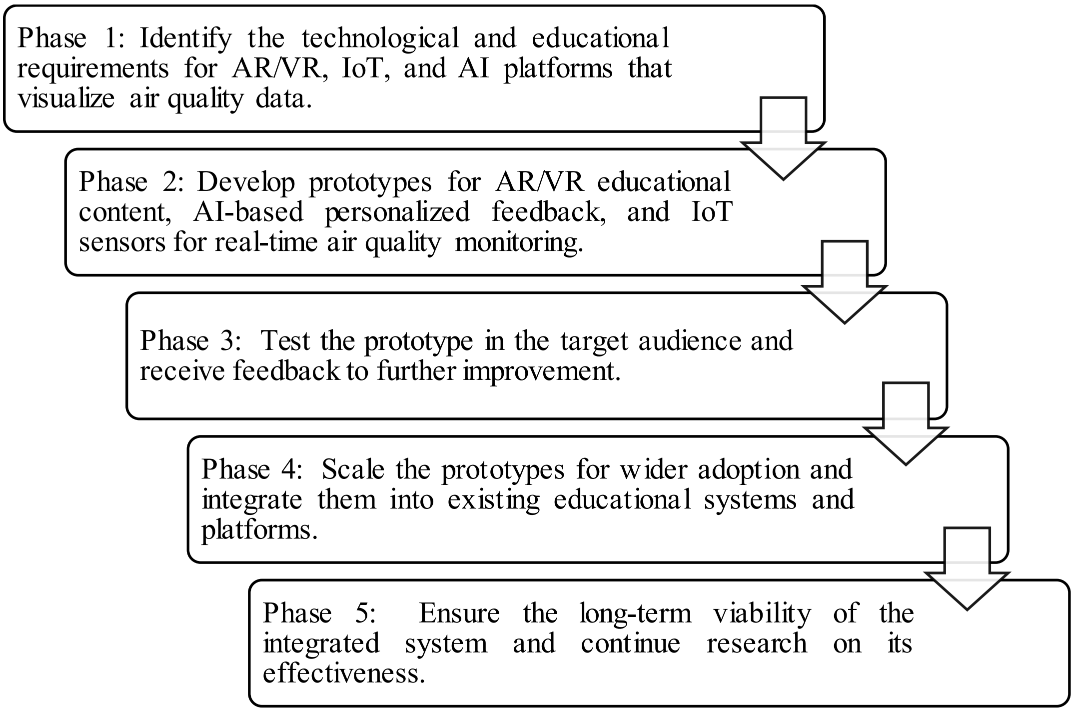


Figure 3.13: Roadmap for implementing AR/VR, AI, and IoT in air quality education integrated with gamification

3.5.3 Application of Learning Theories

A few reviewed studies have incorporated learning theories within their applications to enhance learning outcomes. For instance, Niemeyer et al. (2009)] incorporated Dewey's theory about real-world experiences, role-play, and democratic learning structures. Dewey emphasized the idea of learning through experience (Dewey, 2001). In this study, students engaged with real-world air quality data collected via "Pufftron" air sensors to discuss real pollution issues with their peers. This practice exemplifies Dewey's vision of "learning by doing" and shows how gamification can align with experiential learning principles.

Grossman et al. (2017) applied Captology and the Elaboration Likelihood Model (ELM) to enhance game elements and learning outcomes. Captology focuses on using computers and digital tools to influence behavior (Fogg et al., 2007). ELM explains how persuasion occurs through central (thoughtful) and peripheral (emotional or simple cues) routes (Petty & Briñol, 2011). In this study, Captology principles were used to design engaging feedback systems, like animations and cheering sounds, to reward positive behavior instantly. Participants could customize avatars, promoting personal connection. The use of ELM was focused on peripheral persuasion, using simple visual cues, short motivational messages, and peer competition to encourage adherence. By combining interactive feedback with repetition, the proposed game aimed to build lasting habits and sustain positive behavior change.

Delmas and Kohli (2020) explored how mobile apps can boost user engagement with air quality information and encourage health-protective behaviors by applying the Theory of Planned Behavior and the Theory of Issue Engagement. By stimulating users' intrinsic and extrinsic motivations, the app kept users engaged and improved their understanding of air pollution parameters. Users not only learned more about the health impacts of air pollution but also acted, adjusting their outdoor routines and using air filters to protect themselves.

3.6 Conclusion

This research systematically reviewed the application of gamification for air quality education by gathering data from nineteen papers published between 2009 and 2024. This work identified four delivery methods: augmented reality, smartphones/tablets, laptops/PCs, and portable devices. It also highlighted two main learning objectives: indoor air quality and outdoor air pollution. The Octalysis framework was used to classify the game elements used in the selected studies and their core drives. Sixteen distinct game elements were identified across the reviewed studies. “Accomplishment and Development” was the most frequently used core drive, linked with extrinsic motivation. The most common profiles of trainees are children and adults. All the studies employed digital games on smartphones, tablets, laptops, PCs, AR platforms, and portable devices. Future research should explore practical implementations of AR/VR, such as creating immersive experiences where users interact with real-world air pollution scenarios and view real-time air quality data to make informed decisions. Also, the identified educational theories include John Dewey's Experiential Learning, the Elaboration Likelihood Model for user engagement, the Theory of Planned Behavior for intention and action correlation, and the Citizen Science approach for active user involvement in scientific research.

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STATEMENT OF CONTRIBUTION
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We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Abdollah Baghaei Daemei
Name and title of main supervisor:	Dr Zhenan Feng
In which chapter is the manuscript/published work?	Chapter 4

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]
Abdollah Baghaei Daemei: Writing – review & editing, Writing original draft, Visualization, Resources, Methodology, Investigation, Conceptualization. Zhenan Feng: Writing – review & editing, Supervision, Methodology, Conceptualization. Daniel Paes: Writing – review & editing, Supervision, Conceptualization.

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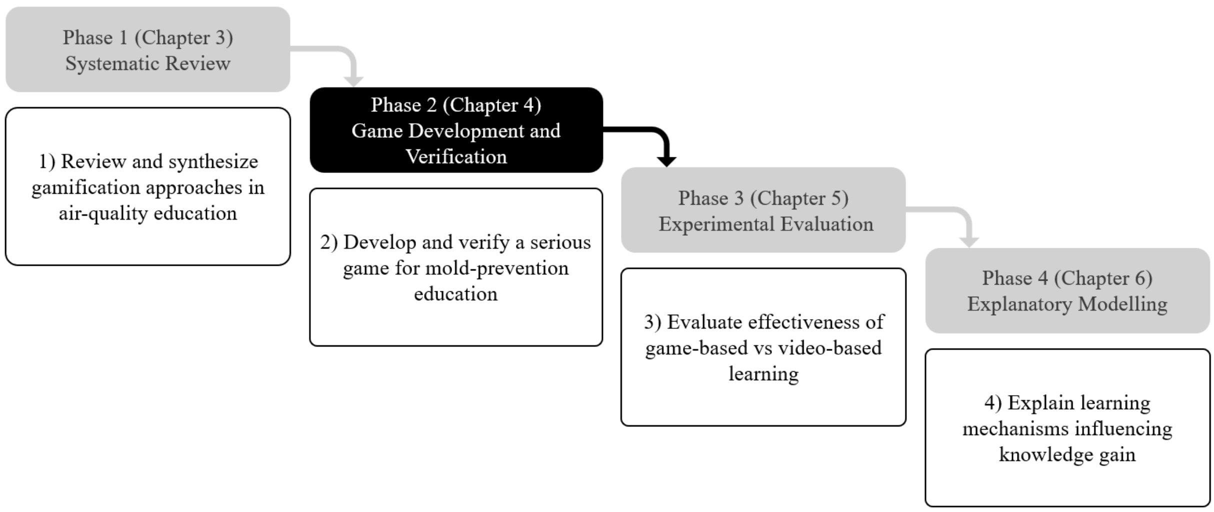
Chapter 4

Serious Game Development

This chapter is based on the following Journal article, which has been published in final form:

Baghaei Daemei, A., Feng, Z., Paes, D. (2025). Developing a Serious Game for Indoor Air Quality and Mold Prevention Education in Residential Buildings, Smart and Sustainable Built Environment, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/SASBE-07-2025-0374.

Building on the systematic literature review presented in Chapter 3, which identified key gaps in the application of game-based learning for air quality education, this chapter translates those insights into the development and validation of a serious game prototype for mold prevention. While Chapter 3 established the conceptual and theoretical foundations, the present chapter (Chapter 4) focuses on operationalizing these principles into a practical educational intervention. The developed prototype subsequently forms the basis for the empirical evaluation reported in Chapter 5.



Chapter 4: Serious Game Development

4.1 Introduction

Indoor air pollution poses significant threats to public health (Li et al., 2019). As pollutants accumulate in the air, they contribute to the deterioration of the air quality, leading to a range of adverse effects (Burnett et al., 2018). When the indoor environment lacks proper ventilation or moisture control, it creates a breeding ground for various pollutants such as mold and dust. According to Klepeis et al. (2001), people spend more than 85% of their time indoors, with 70% of that time spent in residential settings (Tran et al., 2020). Given this high indoor exposure level, the adverse effects of indoor air pollution become even more concerning. Research by Kankaria et al. (2014) indicates that indoor air pollution can be up to ten times more harmful than outdoor pollution, making it a critical environmental and public health issue. It is worth noting that indoor air pollution is ranked among the top five environmental risks (EPA, 2023).

One major contributor to indoor air pollution is mold, a fungus that thrives in damp, poorly ventilated environments. When moisture accumulates, whether from leaks, condensation, or high humidity, mold spores can spread rapidly, contaminating surfaces and releasing airborne particles that compromise air quality. Exposure to mold has been linked to various health problems, including allergies, respiratory infections, and asthma exacerbation (Lelieveld et al., 2015; Silva et al., 2017). Vulnerable populations, such as children, older people, and individuals with preexisting conditions, are particularly at risk (WHO, 2019). Addressing mold growth through proper ventilation, moisture control, and early intervention is crucial to maintaining a healthy indoor environment. This emphasis highlights the need for action to prevent mold growth in residential buildings. Educating individuals and raising their awareness about the sources and consequences of mold is vital. Educating people about mold prevention techniques is of paramount importance due to the direct and profound impact it has on human health (Moreira et al., 2022). Understanding these potential health risks empowers individuals to take proactive measures to minimize exposure (Kim et al., 2024).

One promising technique for delivering effective educational content is through gamification (Douglas & Brauer, 2021; Feng et al., 2023; Johnson et al., 2016). Gamification integrates game-like elements, principles, and mechanics into non-game contexts to engage and motivate individuals (Cai et al., 2025; Oliveira et al., 2023). Integrating educational content into interactive and immersive games can enhance people's awareness in an engaging and safe environment (Behl et al., 2024; Boso et al., 2020; De Jans et al., 2017; Schiavi et al., 2022). In the context of gamification, serious design is used to achieve specific educational or training objectives (Laamarti et al., 2014). Serious games are interactive digital experiences designed with the primary purpose of conveying educational or instructional content while engaging users in gameplay (Breuer & Bente, 2010).

While mold is a known problem, there is limited specific research on effective, engaging educational methods, such as serious games, to empower individuals by providing practical skills. Several studies have explored educational interventions for indoor air pollution, focusing on raising awareness about various environmental parameters, such as volatile organic compounds, carbon monoxide (CO), particulate matter (PM10, PM2.5, PM4.0), ozone, smoke, benzene, and sulfide (Bruno et al., 2020; Campana & Xavier Dominguez, 2020; Mahajan et al., 2020). Much of the research has centered around two primary approaches: raising awareness of air pollution and managing asthma. For instance, Pokric et al. (2015) developed a non-immersive serious game for smartphones, which used real-time data monitoring to enhance users' understanding of their exposure to various pollutants. The results were promising, with participants noting the simplicity of the augmented reality development, its usability, and the overall entertainment value of the game.

Similarly, Campana and Xavier Dominguez (2020) aimed to increase senior high school students' awareness of air pollution through an immersive serious game for tablets and smartphones, which integrated real-time PM measurements. In another study, Kim and Sohanchyk (2022) examined a tablet-based application designed for children aged seven to ten years, which used real-time environmental data to raise awareness of indoor air quality. The application garnered positive initial feedback and increased parental involvement. Likewise, Ling et al. (2021) studied a smartphone-based serious game incorporating a sensor node for data collection to enhance users' understanding of air pollution. The feedback from participants was encouraging, with 60% of trainees expressing a willingness to continue using the app.

Another significant focus has been on managing asthma through interactive and educational interventions. Studies have explored how serious games can assist individuals, particularly children, in managing their asthma. Thomson et al. (2017) investigated children's understanding of asthma clinical outcomes using a serious game integrated into a tablet application that included air quality monitors and spirometers. The results indicated that users were more engaged, and children rated the app as fun and somewhat helpful, with the exploration within the game being particularly enjoyable. Similarly, Grossman et al. (2017) developed a smartphone application to promote daily asthma control as a routine behavior. The app educated users about the importance of air quality while integrating a dose-counter spirometer to help track asthma medication usage over time.

In a more targeted approach, Kim et al. (2021) studied children aged eight to twelve years, helping them track their asthma condition and encouraging them to use a spirometer. Their smartphone app, which featured an indoor air quality sensor, customized emojis and characters to trigger motivation, and a history tracker with a chatbot for answering questions, aimed to make asthma management more engaging and personalized. Building on this, S. Kim et al. (2022) developed a smartphone application that interacted with real-time IAQ data to help users improve their indoor environment and identify asthma triggers. While the app's graphical interface received positive initial feedback, its use declined over time due to a lack of interactivity and fun, highlighting the need for more engaging features to encourage continued usage.

Some studies used digital technologies such as Augmented Reality or Virtual Reality to educate individuals about air pollution. For instance, Pokric et al. (2015) utilized a non-immersive serious game application for smartphones, using real-time data monitoring to teach users about air pollution and its effect on human health. Similarly, Campana and Xavier Dominguez (2020) developed an immersive serious game for tablet or smartphone with real-time PM measurements to increase users' awareness and understanding of air pollution, as well as teach them about potential risks. Regarding the long-term impact and knowledge retention of serious games, Liyuan Hu et al. (2021) compared medical students who trained using the NEOGAMES serious game against those in a traditional control group. While short-term knowledge gains were limited, results at 6-month follow-up revealed substantially higher retention among participants in the game group, nearly three times the retention compared to controls. Also, Chittaro and Buttussi (2015) demonstrated that an immersive serious game significantly outperformed a traditional safety card in enhancing long-term knowledge retention about aviation safety, with participants maintaining their post-test performance even after one week, highlighting the role of emotional engagement and physiological arousal in sustained learning outcomes.

Although substantial research has been conducted on indoor air quality-related issues, a notable gap exists in mold prevention. Despite the well-documented health risks associated with mold exposure and the widespread nature of the problem, no study has specifically explored the potential of serious games to educate individuals on mold prevention in indoor environments (Abdollah Baghaei Daemei, Ruggiero Lovreglio, et al., 2025). Therefore, this study represents one of the first efforts to address this gap by developing an interactive educational game to educate individuals with practical skills to prevent mold growth in residential buildings.

As such, the primary aim of this study is twofold: first, to prototype a serious game designed to educate people on preventing mold growth in residential buildings, and second, to verify the educational content of the game through a semi-structured interview (see Appendix D for further details) and home visit investigation. This research presents the practical steps and knowledge required to develop a serious game prototype to raise people's awareness of indoor air quality.

4.2 Methodology

This section outlines the research design, game development process, and evaluation approach. The study uses a single-arm experimental design, where participants completed a pre-test, engaged with the serious game, and then completed a post-test. The methodology also includes details about how knowledge was assessed across multiple domains, how responses were scored, and the tools and statistical tests used for analysis.

4.2.1 Learning Objectives and Educational Content

The game has four learning objectives (LOs) designed based on Bloom's Taxonomy (Krathwohl, 2002), focusing on the first three cognitive levels: Remember, Understand, and Apply. This framework ensures structured learning progression, guiding players from basic knowledge acquisition to practical application in real-life scenarios. Bloom's Taxonomy levels associated with each learning objective (LO) are presented as follows:

- Remember (LO1 & LO2): The first level of Bloom's Taxonomy involves recalling facts and recognizing key information. LO1 requires players to identify specific spots in the kitchen, bedroom, and bathroom where mold will likely grow, reinforcing memory-based recognition of mold-prone areas. Similarly, LO2 focuses on recalling the essential elements of mold formation—temperature, humidity, spores, and nutrients—helping players establish foundational knowledge of mold growth conditions.
- Understand (LO3): The second level emphasizes comprehension and the ability to explain concepts. LO3 requires players to understand how specific environmental conditions, such as temperature and humidity, contribute to mold growth. This goes beyond memorization by enabling players to connect different factors and predict when and where mold will likely develop.

- Apply (LO4): The third level involves using acquired knowledge in real-world contexts. LO4 focuses on applying strategies to prevent mold growth in residential buildings. This requires players to take what they have learned about mold-prone areas, essential growth factors, and environmental conditions, and translate that knowledge into actionable steps for maintaining a healthier indoor environment.

The target audience for this serious game comprised the general public adults across New Zealand, including homeowners, renters, and individuals living in diverse housing conditions. The game was designed to be accessible to a broad demographic, ensuring ease of use regardless of players' technical skills or prior knowledge of mold prevention. This is supported by several studies reporting that more than half of New Zealand rental houses had visible mold (BRANZ, 2015; Consumer, 2023).

First, users will learn to identify spots where mold can likely occur (LO1). They will learn the key factors contributing to mold formation (LO2). Additionally, the game will cover the optimal temperature, and humidity ranges necessary to prevent mold growth (LO3). Finally, users will be taught effective strategies for mold prevention (LO4). The learning objectives and educational content were developed based on official public sources, including relevant governmental regulations, standards, building codes, and international publications, as described in the following paragraphs. This ensures that the learning objectives and educational content are aligned with established and evidence-based knowledge rather than general assumptions. Notably, each LO corresponds to each level in the game (Figure 4.1). Therefore, users can progress by completing one level after another, advancing their understanding and knowledge about mold prevention.

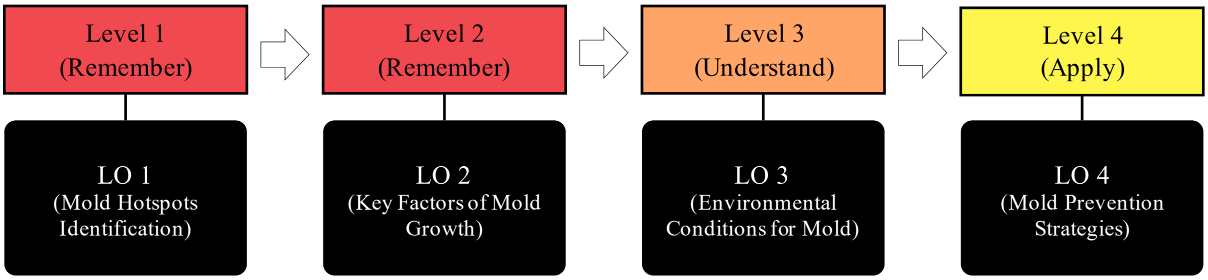


Figure 4.1: The sequence of the levels according to the LOs

For LO1, the identified zones and spots for potential mold growth include the kitchen, bedroom, and bathroom. In the kitchen, key areas are the kitchen bench (countertop) (Brambilla et al., 2022), windows, and sinks (An & Yamamoto, 2016). In the bedroom, mold-prone spots include windows (Brambilla et al., 2022), walls, and cupboards (wardrobe and closet) (Arumala, 2006;

Small, 2003), ceiling corners (Mahooti-Brooks et al., 2004), behind curtains and behind furniture (Stachniewicz, 2018). In bathrooms, mold commonly develops on window reveals and windowsills (Arumala, 2006; Stachniewicz, 2018) and in upper room corners (Robbins & Morrell, 2017), while in the broader dwelling it is also frequently found in carpets, textiles, and areas associated with cooking and laundering. For LO2, we found the key components of mold formation, including temperature, humidity, spores, and nutrients, across the published literature (Du et al., 2021; Northolt & Bullerman, 1982). The educational content for LO3 encompasses the optimal ranges of temperature and humidity to prevent mold growth. For optimum occupant comfort and health, a humidity of 40-60% (BRANZ, 2019b; LEVEL, 2023) and an indoor temperature between 18-22°C is recommended (BRANZ, 2019a; Building Performance, 2023; Plagmann, 2019). Finally, for LO4, we identified 15 strategies among several official sources. Among those strategies, we will apply the most practical and effective ones within the game. Public sources in New Zealand suggest several solutions to reduce moisture and condensation. These include wiping condensation off windows and walls, and opening windows. It's recommended to avoid using portable gas heaters or unflued gas heaters. Hang washing outside to dry and use lids on pots while cooking. Additionally, fans and rangehoods should be used to ventilate. Limit moisture sources such as fish tanks and indoor plants. Install ventilation systems and use dehumidifiers. Vent driers outside and improve heating and insulation in the house. Pull beds and furniture away from walls, leave wardrobes slightly open, and open curtains during the day (1News, 2023; Allergy New Zealand, 2022; Building Performance, 2023; Consumer, 2022; Kāinga Ora, 2023).

4.2.2 Serious Game Prototype Development

The prototyping workflow for the serious game adhered to a structured process, as illustrated in Figure 4.2. It commenced with identifying learning objectives, establishing the core knowledge and skills the game aimed to impart. Subsequently, educational content was developed through a literature review to align with best practices and research findings. Thereafter, game mechanisms were designed, incorporating principles from the Octalysis framework. In line with that, some research highlights successful applications of the Octalysis Framework. A study by Lozano et al. (2023) developed a mobile application for mathematical learning, incorporating game-based learning principles with Octalysis-driven mechanics. Evaluations showed improved engagement and effectiveness in knowledge retention. Mentzelopoulos et al. (2015) explored a role-playing simulation platform structured around the Octalysis Framework, providing educators with interactive role-play simulations featuring virtual humans to enhance learning experiences. The results underscored the framework's utility in immersive educational simulations. Furthermore, a classification study on stress management mHealth applications examined how the Octalysis Framework helps map motivational elements in health-related apps, emphasizing user engagement and adherence (Ewais & Alluhaidan, 2015). The following step involved developing the game's storyline and crafting a narrative reinforcing the learning objectives. Once the structure was in place, the prototype was developed using Storyline 360, translating the conceptual design into an interactive format. This initial version was verified and tested for alignment with learning goals through semi-structured interviews and home-visit investigations. Finally, refinements were made based on verification outcomes, ensuring the game met its intended objectives before final implementation.

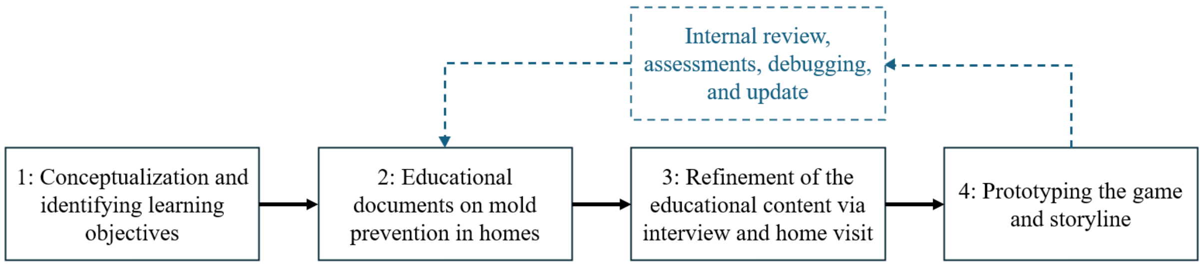


Figure 4.2: The prototyping workflow

4.2.2.1 Game Mechanics

To identify the game mechanics, the research team applied the Octalysis Gamification Design Theory principles (Chou, 2015) to enhance engagement and motivation (Table 4.1). This theory proposes game mechanics aligned with intrinsic and extrinsic motivators, which can engage and motivate players while delivering educational content. The mechanics are designed to ensure players engage with each scene sequentially, requiring them to complete one scene before unlocking the next. This rule guides the player's progression and reinforces learning by gradually introducing more complex challenges and information as they advance through the levels, aligning with the learning objectives. Reward systems in the game involve incentives, including points and stars that players earn for completing tasks and reaching goals or a certain level. Points are earned for correct choices and deducted for incorrect ones, with a maximum of 10 points and a reduction of 3 points to maintain motivation. Performance is also visually represented through stars awarded at the end of each scene and level (Figure 4.3).

Table 4.1: The selected game mechanics incorporated into the game are aligned with the Gamification Design Framework (Octalysis) developed by (Chou, 2015)

CDs	Mechanics	Explanation/Usage
CD 1: Meaning	Narrative	Narrative refers to the storyline and context that immerses players in the learning experience. It integrates characters, scenarios, and challenges that provide a real-world framework for players to explore through a compelling story.
	Higher Meaning	It provides players with a sense of purpose beyond the game itself. Players are motivated not just by the game's rewards, but by the belief that their actions contribute to a greater cause or have real-world significance.
CD 2: Accomplishment	Points	Points are a form of extrinsic reward that recognizes player's actions and achievements.
	Progress Bar	The progress bar visually represents how far the player has completed a task or mission.
	Quest Lists	Quest lists outline tasks or challenges that guide the player's journey.
	Step-by-Step Tutorial	The tutorial breaks down tasks and teaches the player how to succeed in the game.
	LevelUp Symphony	Whenever you level up, you acquire a new set of skills.
CD 3: Empowerment	Milestone Unlock	It represents a key achievement or significant event in the game that rewards the player with new content and levels. It marks the completion of a specific set of tasks.
	Instant Feedback	The immediate responses players receive based on their actions or decisions in the game.
CD 4: Ownership	Avatar	A customizable digital representation of the player within the game.
CD 5: Social Influence	Mentorship	It refers to a guidance system where an experienced character (a virtual character) provides the player with advice, support, and knowledge.

CD 7: Unpredictability	Visual Storytelling	This mechanic uses images, animations, and design elements to convey the game's narrative and themes. Rather than relying on text or dialogue, it communicates key messages, emotions, and ideas through art style, character design, environments, and visual cues.
CD 8: Avoidance	Progress Loss	It refers to the mechanic where players lose some in-game points after failing the task or challenge.

a

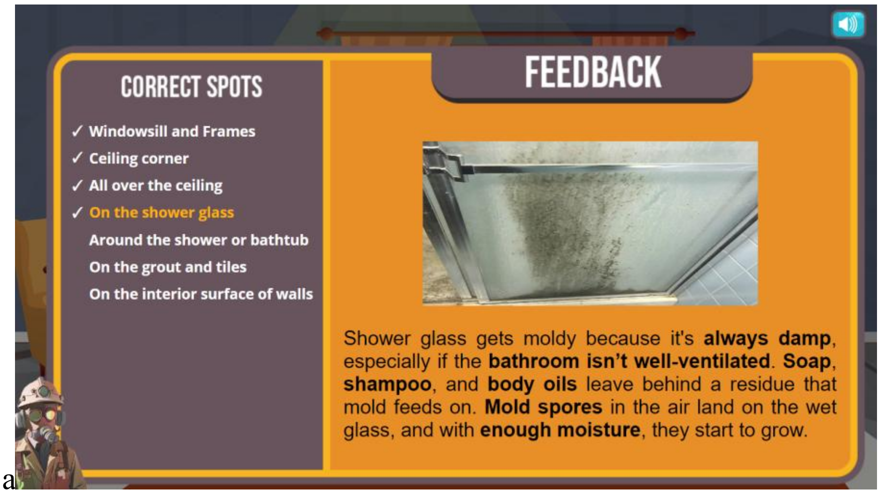
b

Figure 4.3: The in-game reward system. Based on participants' performance

Feedback loops in the game provide both instant and overall responses to user actions. Instant feedback appears immediately after each choice, awarding or deducting points, changing hotspot colors (green for correct, red for incorrect), and playing audio cues. Overall feedback is given at the end of each level through a pop-up panel that explains the rationale behind correct and incorrect answers and summarizes the user's final score. For example, in Level 1, hovering over a hotspot reveals a tooltip with its name and image, and selecting it triggers an immediate visual and audio response, reinforcing learning before the next task (Figure 4.4).

Figure 4.4: Displaying instant feedback for each participant's response by showing a pop-up notification

Also, the feedback gallery serves as the main delivery console and approach for feedback throughout the game (see Figure 4.5). After completing each task, users are directed to the feedback gallery, where they can read the rationale behind their choices. This feedback mechanism ensures players understand why certain decisions were correct or incorrect, reinforcing learning. Importantly, users cannot skip this section; each piece of feedback must be read before proceeding. Once all the feedback sections are reviewed, a "Next" button directs players to the next scene, task, or level. This structure ensures that the educational content is delivered equally to all players, guaranteeing they receive the same guidance and understanding before advancing.

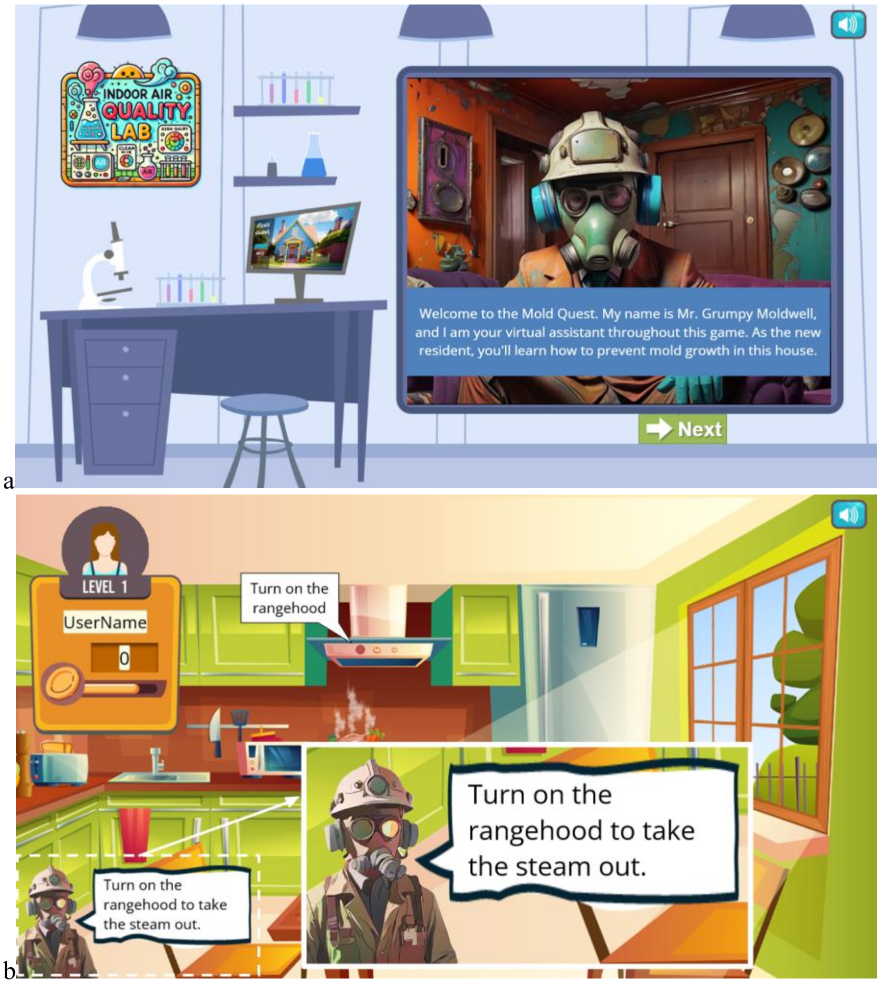


a

b

Figure 4.5: After completing each level, participants are redirected to the Feedback Gallery Interface

The game's narrative revolves around "Mr. Grumpy Moldwell", a virtual assistant who guides the players through the game experience. Mr. Grumpy Moldwell provides essential tips and instructions throughout the game. His guidance is delivered through textual prompts and audio (speech) instructions at a moderate speaking pace to ensure clarity and ease of understanding. Guidance will appear as pop-ups before each scene and level, with "Next" and "Back" buttons allowing players to review the instructions as needed (Figure 4.6).



a b

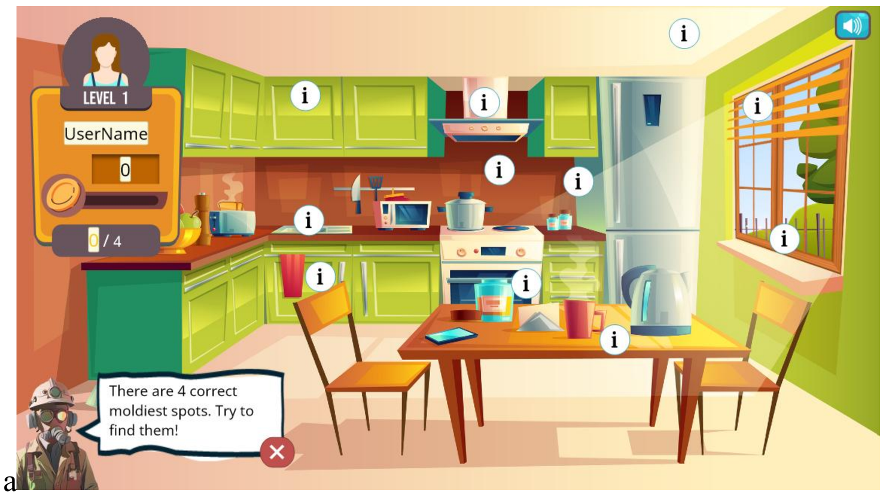
Figure 4.6: Before each level, the main virtual assistant ("Mr. Grumpy Moldwell") presents essential tips

The game allows for personalized experience by incorporating an avatar selection feature and a text box where users can input their preferred names. Both the avatar and the chosen name are displayed in the status panel, creating a more engaging experience (Waltemate et al., 2018). Selecting a preferred avatar and typing a preferred name are mandatory steps before proceeding to the next stage of the game. A status panel was included in the top left corner of each scene, displaying the user's chosen avatar, preferred name, gained scores, progress bar, and the number of tasks they need to accomplish (see Figure 4.7).

Figure 4.7: At the beginning of the game, participants select their preferred avatars and enter their name (a).

4.2.2.2 Narrative and Storyline

Players explore a typical house in New Zealand, focusing on three key rooms: the kitchen, bedroom, and bathroom (see Figure 4.8). As new residents, users learn how to prevent mold growth through a structured, sequential gameplay experience. The game is divided into four levels, each aligned with a specific learning objective. Players must complete one level before unlocking the next to progress, ensuring a step-by-step approach rather than random access. Each level begins with instructions and tips to guide players, followed by immediate feedback on their choices at the end of each scene.



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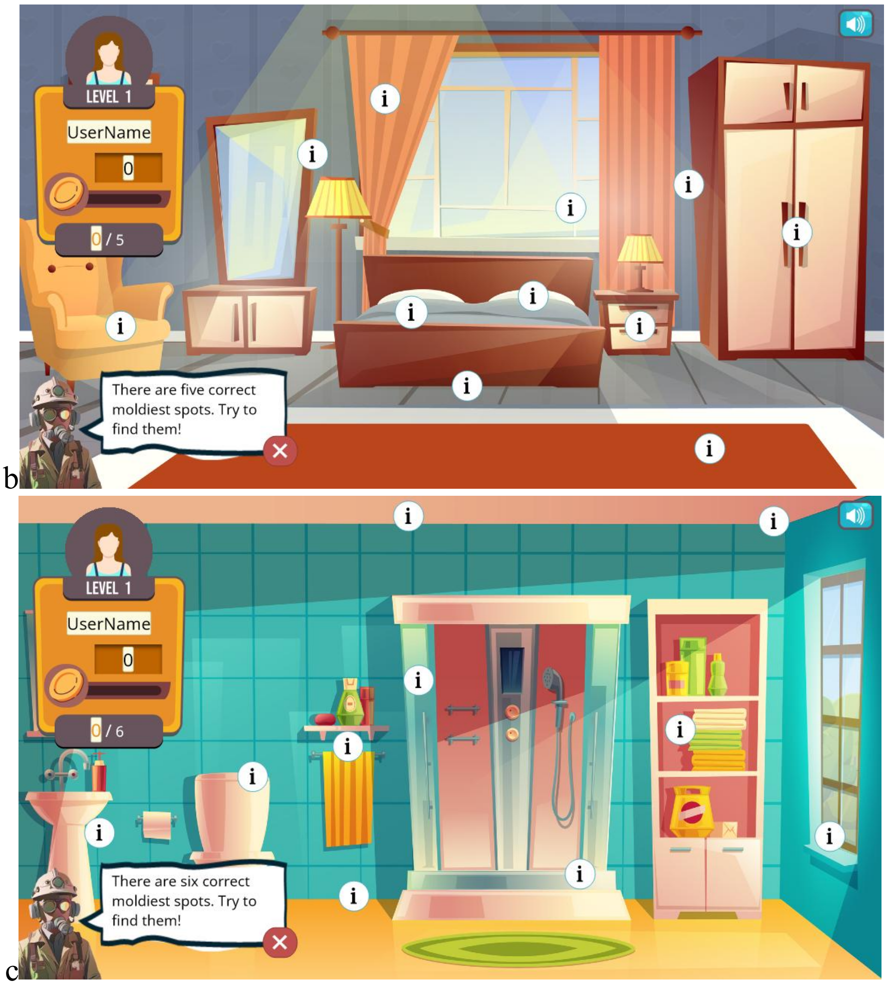


Figure 4.8: In Level 1, participants are tasked with identifying the moldiest spots within three different environments

The game takes place in a realistic setting where players move into a newly acquired New Zealand house at risk of mold growth. After an introductory briefing on mold prevention and the game's goals, players progress through levels representing different rooms, each with specific challenges. They apply knowledge learned in earlier levels to identify mold-prone areas, adjust environmental conditions, and implement prevention strategies. The final level reviews the entire house, requiring players to apply all learned techniques, followed by a performance summary and feedback. The step-by-step structure ensures gradual skill development, while the narrative keeps players engaged by linking decisions to visible outcomes. Designed for independent play, the game integrates all instructions and guidance within the gameplay. Story elements are revealed through dialogue, visual cues, and feedback, with interactive tasks such as selecting hotspots, receiving instant and overall feedback, and tracking scores. This structure combines practical learning with an immersive, scenario-based experience.

Regarding game dynamics and activity types, each level incorporates interactive tasks designed to engage users and reinforce learning. In Level 1, players are presented with hotspots, each containing either a correct or incorrect mold-prone spot. Users must select based on the given scenario, with immediate feedback on whether their choice is correct or incorrect. Upon completing the requested tasks, a "Completed" button will appear under the status panel (Figure 4.9). Users must click on this button to view their overall collected points. They can track their accumulated points from this screen and proceed to the Feedback Loop (Figure 4.9). This action is the same for all levels.

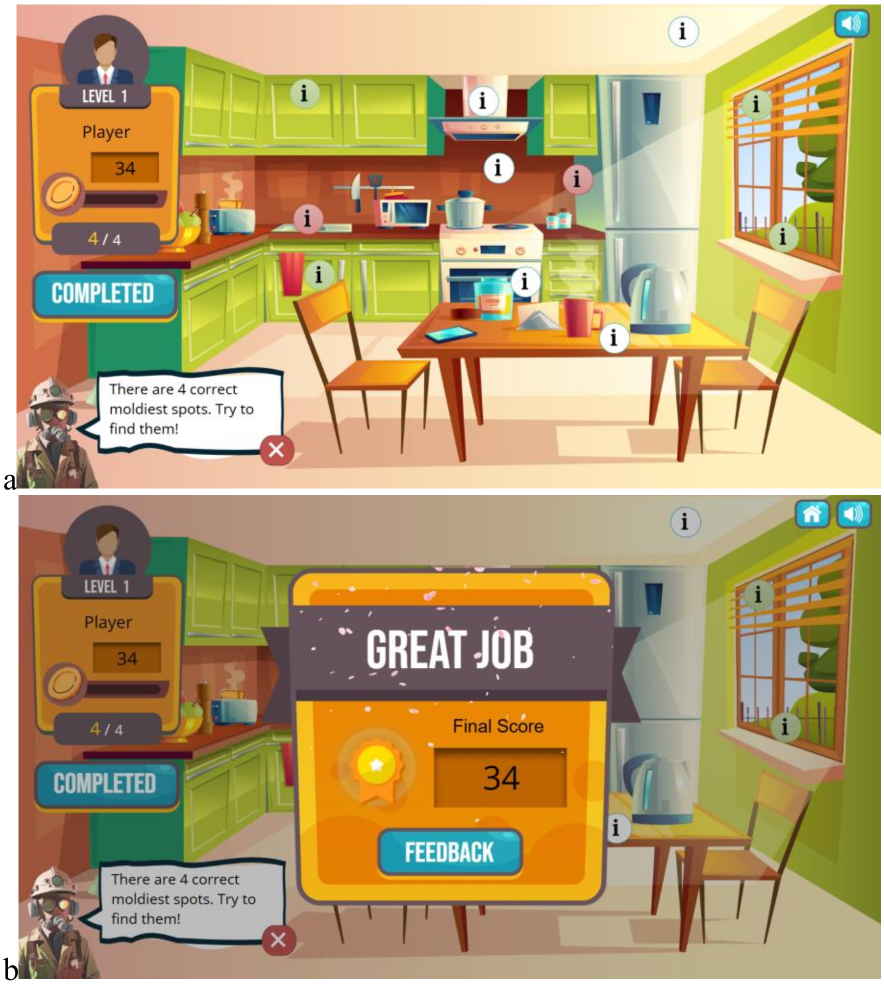


Figure 4.9: Upon completing the assigned task, a "Completed" button indicates task completion

For Level 2, a free-form drag-and-drop activity was designed, consisting of eight correct and four incorrect items. Players must drag and drop the items into the appropriate boxes on the right side of the screen. As each item is placed in the correct or incorrect spot, instant feedback is provided by changing the item's color to green for correct placements and red for incorrect ones. This activity aims to educate individuals by providing immediate feedback rather than testing their knowledge or penalizing them through point deductions for multiple attempts. Additionally, as players place each item, the status panel dynamically updates to reflect the remaining task progress, offering another layer of visual feedback. Once all items have been correctly placed, a Submit button appears in the center of the screen, allowing players to complete the task and review their final feedback. Upon submission, players receive 10 points as a reward for correctly arranging all the items (Figure 4.10).

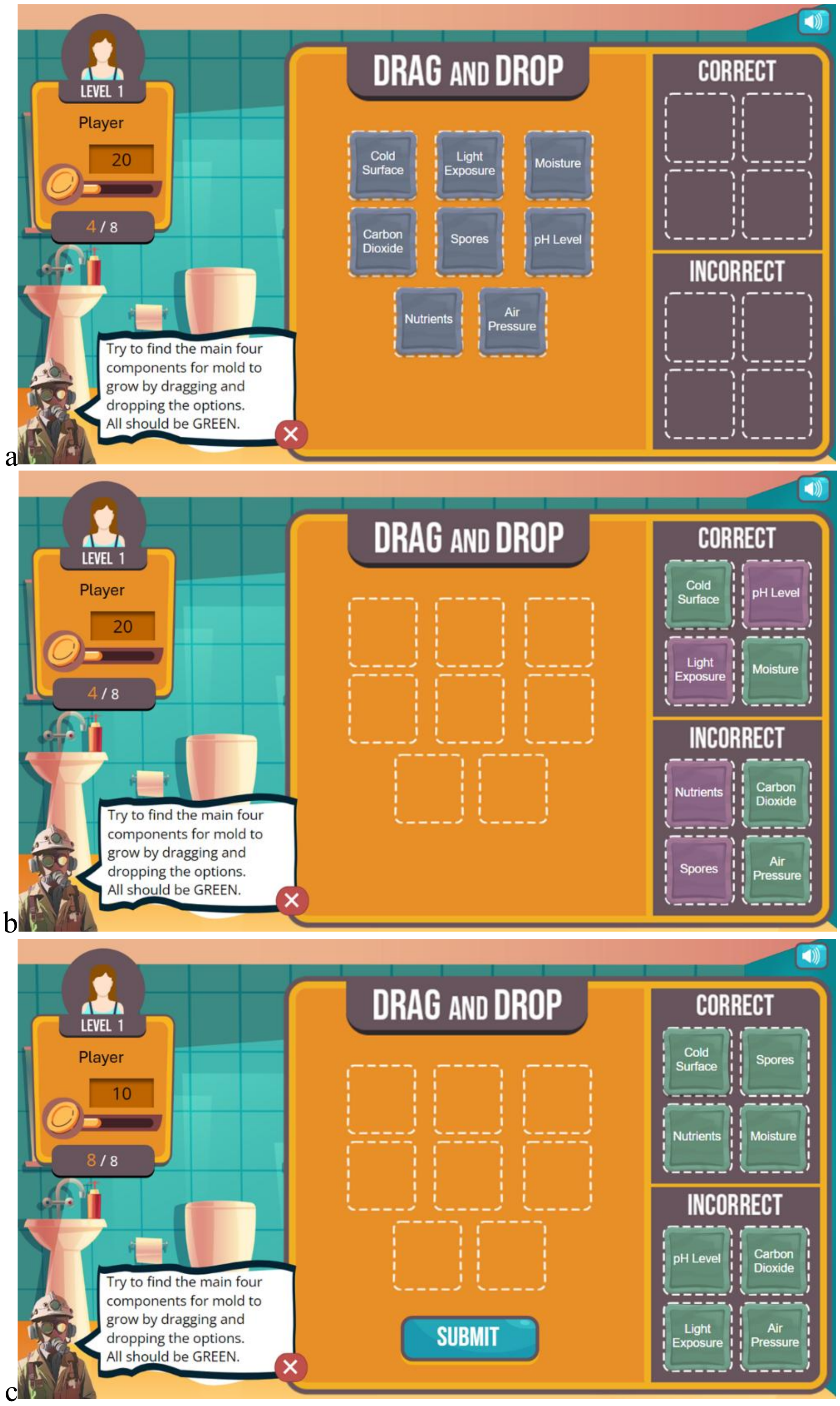
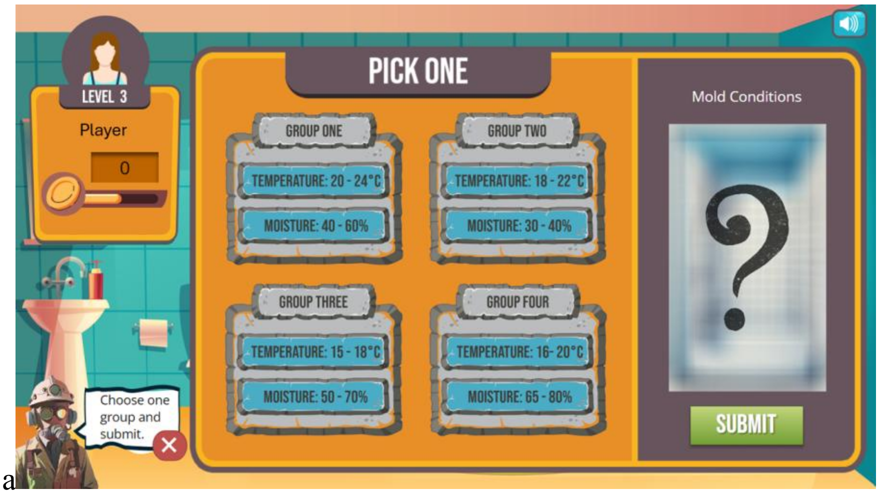


Figure 4.10: Drag-and-drop activity in Level 2 (a). Participants must identify and place the four correct items related to mold formation from a set of eight

In Level 3, the activity is called "Pick One." Users must choose from four groups representing different temperature and humidity conditions, designed as interactive buttons. Users can select only one group and submit their response. If they choose an incorrect group, a dialogue box appears, providing instant feedback on why their choice is incorrect and guiding them to retry until they select the correct group. Once they identify and submit the correct group, they receive 10 points, and another dialogue box appears, explaining the feedback and redirecting them to the next level (Figure 4.11).



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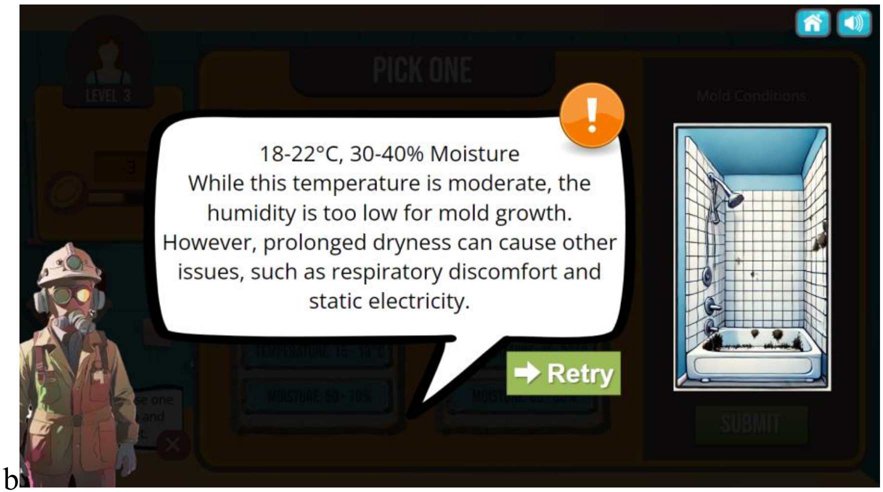

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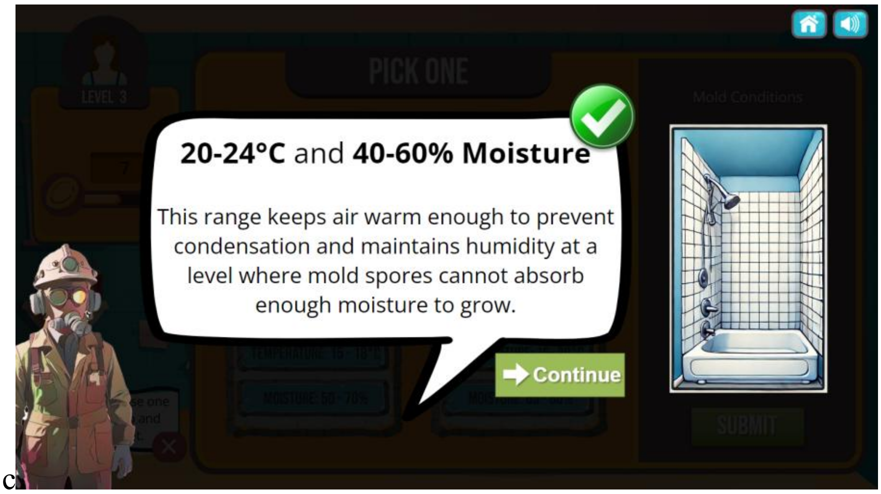


Figure 4.11: In Level 3, participants select the appropriate temperature and humidity range from four available groups

In Level 4, the activity focuses on applying various strategies. Initially, the first scene presents nine strategies, but only one is active at a time, while the others remain disabled. Players must complete each activity sequentially before proceeding to the next one (Figure 4.12). The activities are designed to align with the nature of each strategy. For example, in the first strategy, opening the window for 15 minutes daily, players are presented with a bathroom scene where steam appears on the screen. To complete the task, they must click on the window, triggering an animation that shows the steam dissipating. Once completed, they can move on to the next strategy. Strategy 4 is venting the dryer outside is an example to elaborate on this task. In this activity, players are presented with a laundry room scene where an uninstalled duct is visible. They fix the ventilation system by placing the duct piece into the highlighted area. Once correctly installed, the system is properly vented, allowing players to progress to the next strategy. Another example is Strategy 5: Better heating and insulating the house. In this activity, players first receive two instructional dialogues explaining the purpose of the task. Then, they are shown a house with pulsating markers on the walls and roof, indicating where insulation needs to be placed. Players apply insulation by clicking on these areas to improve the house's warmth. Upon completing the task, a temperature indicator updates to reflect a warmer indoor environment, and players are rewarded with 10 points before unlocking the following strategy (Figure 4.12).

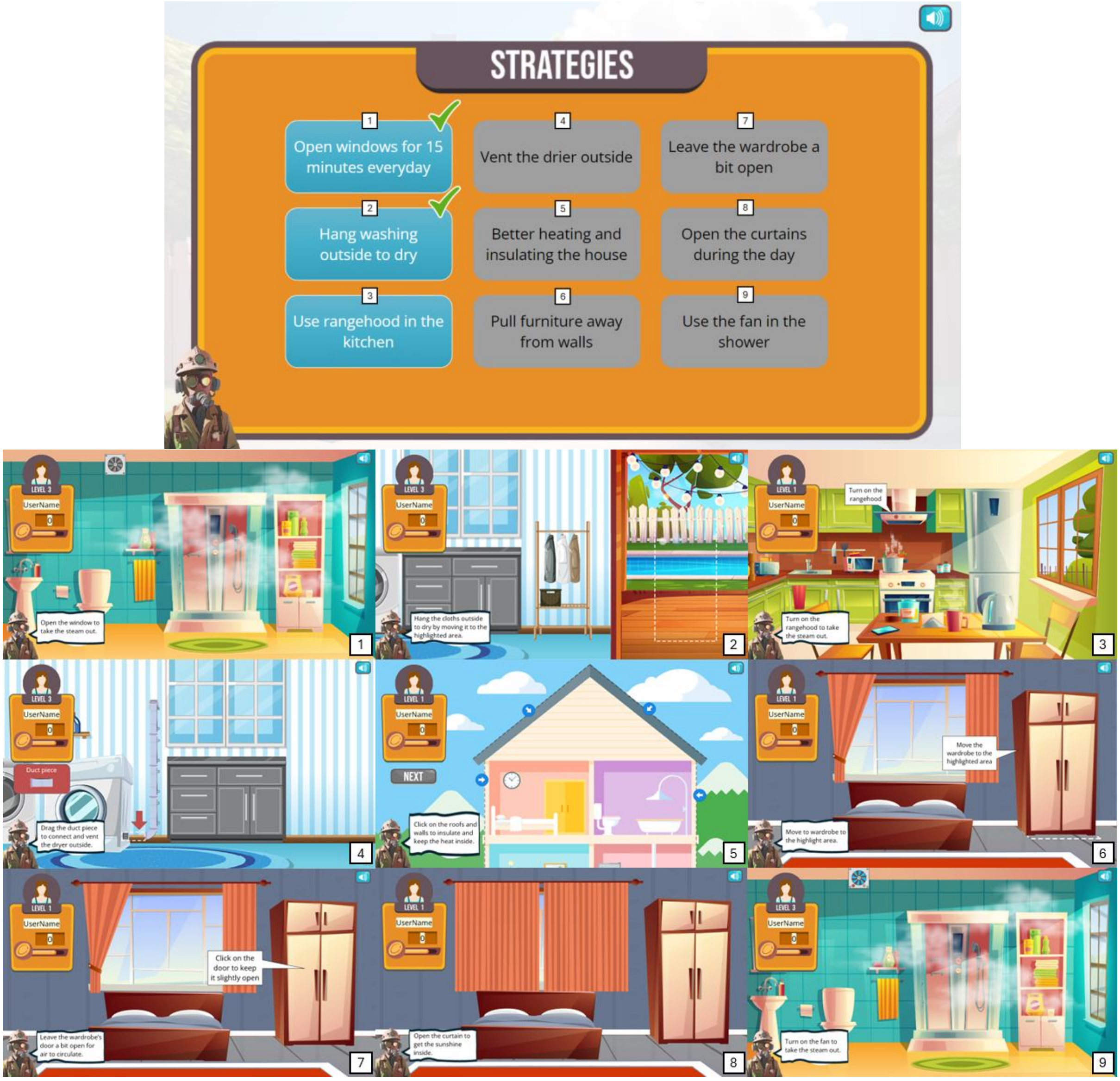


Figure 4.12: Level 4 presents nine essential strategies for preventing mold growth.

By applying specific mold prevention strategies, users can actively engage in decision-making activities, such as dragging and dropping objects (e.g., placing lids on pots or pulling the bed away from the wall) or interacting with in-game elements (e.g., turning on the rangehood or exhaust fan). As users make decisions, they will see the immediate impact of their actions on the reduction of moisture and mold risk, visually represented by changes in the mold risk and humidity levels. This interactive approach helps reinforce the effectiveness of different strategies in managing indoor environmental conditions to prevent mold growth.

4.3 Serious Game System Design

Storyline 360 provides an easy-to-use design interface while offering powerful interactivity through built-in triggers and the ability to use JavaScript for custom features. In this game, we used if conditions, triggers, and variables to create interactive elements, and JavaScript code to animate the shapes and objects. By combining these tools, the research team built a dynamic experience where the game adapts to the player's decisions, offering immediate feedback and unlocking new content as they move through each level. This tool was key to developing the sequential, task-based structure and implementing interactivities such as clickable areas, feedback systems, and scoring mechanisms. The development followed a waterfall approach, a structured, sequential design model that involves distinct phases such as requirements analysis, design, implementation, testing, and maintenance. This approach ensured a clear and systematic framework for the creation of an educational game focused on mold prevention (Kramer, 2018). Figure 4.13 illustrates the game story view.

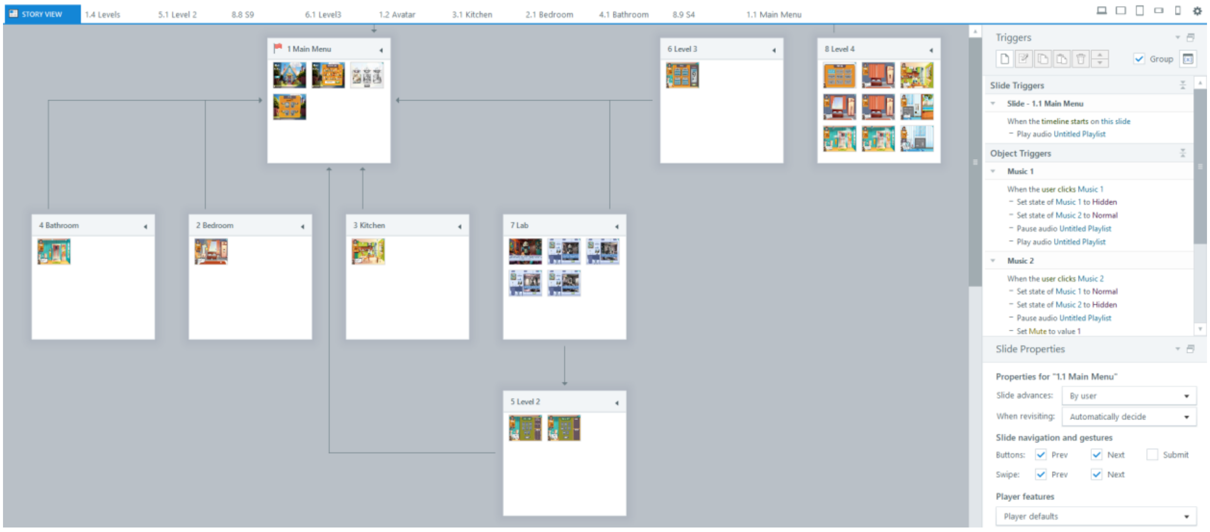


Figure 4.13: The game story view displays the whole sequence of slides and interactions within the Storyline 360 software

4.3.1 Platform and Accessibility

The game is accessible on PCs, laptops, tablets, and smartphones, ensuring cross-platform compatibility and broad reach. Designed for independent play, it enables users to progress at their own pace without supervision. All necessary guidance, instructions, and tips are embedded within the gameplay to support users with diverse educational backgrounds and varying levels of experience with digital games. The final product is delivered in HTML format, eliminating the need for installation.

4.3.2 Visuals and Graphics

The game adopts a 2D cartoon-style design to ensure accessibility for a broad range of players, including those with limited experience in complex video games. This visual approach is engaging yet straightforward, providing a clear and easy-to-navigate interface. Images, pop-up elements, and background scenes were sourced from the open-access Freepik platform (www.freepik.com) and subsequently customized using Adobe InDesign and Photoshop to align with the game's aesthetic and educational objectives.

4.3.3 Audio and Sound

The game incorporates minimal yet effective audio elements, including background sounds to create an immersive environment and sound effects to indicate correct or incorrect responses. These cues reinforce learning and enhance the interactive experience. Voiceovers were produced using the Eleven Labs AI text-to-speech generator (www.elevenlabs.io) to deliver clear, realistic instructions. Mini Movie Maker (Windows version) was used to combine short video clips with the generated audio. Audio is primarily featured in the Indoor Air Quality Lab (left image in Fig. 6), where the virtual assistant, Mr. Grumpy Moldwell, provides essential guidance before players enter the interactive scenes. Subtle background music further enriches the atmosphere, with pause and mute options for user control. As players progress, positive sounds are played when points are earned, while error cues signal point deductions. Upon completing a task, a distinctive accomplishment sound marks the successful completion of the level, providing positive reinforcement and encouraging continued engagement.

4.3.4 Language and Textual Information

The language in the game is simple, with no slang, to ensure it is accessible to international audiences and non-native English speakers. Textual instructions and feedback are designed to be direct, offering step-by-step guidance. The text is presented alongside visual cues, making it easier for users to understand and retain the information.

4.3.5 User Interface and Interaction

The game's user interface (UI) is designed to be intuitive and personalized. Players select an avatar and enter their name, which is displayed throughout the game to maintain engagement and create a stronger connection with the content. A status panel in the top-left corner tracks points, tasks, avatar, name, and progress, serving as a constant guide and providing an overview of achievements and next steps. Gameplay is primarily task-based, with players completing objectives to advance through levels. In Level 1, they identify mold-prone areas in kitchens, bedrooms, and bathrooms by selecting highlighted spots, earning points for correct choices and losing points for incorrect ones. Level 2 presents multiple-choice questions on key elements required for mold growth. Levels 3 and 4 involve adjusting sliders and applying prevention strategies learned earlier. Each level builds on the previous one, promoting structured progression and reinforcing learning objectives. Interactive mechanics—such as hotspot selection and temperature/humidity adjustments—encourage experimentation and learning through trial and error, supported by a feedback system that provides immediate responses to player actions.

4.4 Prototype Verification on Learning Objectives

After developing a preliminary prototype, a verification step was conducted to ensure the prototype meets design specifications. The verification step involved semi-structured interviews and home-visit observations. In the interviews, the interviewees were presented with the preliminary prototype and gave feedback and comments on the game content. In the home visits, mold-prone areas and cases were investigated in residential buildings, offering real-world context and verification to the game.

4.4.1 Interview with Experts

The invitation process began with an online invitation via email, with meeting schedules facilitated through the Doodle platform (www.doodle.com). The interviews were held on Microsoft Teams, lasting approximately 40 minutes for each participant. Video recordings and transcriptions were obtained using Microsoft Teams. NVivo was utilized for coding and thematic analysis, which allowed for an examination of the qualitative data. The research team contacted over 60 IAQ experts in New Zealand via email invitations, with twelve responding and agreeing to participate in the interview. The participants received a detailed participation information sheet outlining the study's purpose, procedures, and ethical considerations. Before organizing the interview sessions, all participants had to sign a consent form, ensuring their informed participation agreement. Table 4.2 provides the interviewees' demographic information.

Table 4.2: Interviewees' demographics

Category	Subcategory	Percentage (%)
Age	25–34 years	9.1 (N=1)

	35–44 years	36.4 (*N*=4)
	45–54 years	27.3 (*N*=4)
	55–64 years	27.3 (*N*=3)
Gender	Female	36.4 (*N*=5)
	Male	63.6 (*N*=7)
Education	Associate degrees	18.2 (*N*=1)
	Bachelor's degrees	18.2 (*N*=3)
	Master's degrees	27.3 (*N*=4)
	Doctoral	36.4 (*N*=4)
Profession	Advisor	8.33 (*N*=1)
	Building Scientist	16.67(*N*=2)
	Senior Lecturer	8.33 (*N*=1)
	Housing Assessor	8.33 (*N*=1)
	Sustainability Specialist	16.67 (*N*=2)
	Research Scientist	16.67 (*N*=2)
	Architect	8.33 (*N*=1)
	Senior Technician	8.33 (*N*=1)
Experience	1–5 years	9.1 (*N*=1)
	6–10 years	18.2 (*N*=2)
	11–15 years	27.3 (*N*=2)
	Over 16 years	45.5 (*N*=7)

Table 2 presents the diverse backgrounds, professions, and educational experiences of the interviewees, ensuring that insights were drawn from both industry and academic perspectives. Participants included building advisors, building scientists, university lecturers, housing assessors, sustainability specialists, researchers, architects, and senior technicians. The interview comprised five parts, covering the four learning objectives (LOs) and general game content. In Part 1, participants assessed whether the game accurately represented common mold-prone areas in kitchens, bedrooms, and bathrooms, and suggested additional rooms (e.g., living rooms) or overlooked spots. Part 2 examined the clarity and relevance of the options provided for mold formation, inviting suggestions for additional information to enhance user understanding. In Part 3, participants evaluated whether the temperature and humidity ranges were realistic and proposed effective communication strategies for preventing mold growth in residential buildings. Part 4 sought input on additional strategies to enhance learners' understanding of mold prevention and on the practicality of simulating kitchens, bedrooms, and bathrooms for users to apply these strategies. Finally, Part 5 explored the game's overall strengths and key takeaways, while giving participants the opportunity to share further insights or recommendations not addressed in earlier questions.

4.4.2 Home-visit Investigation

The home-visit investigation consists of visiting six homes to validate the content collected from the interviews. A key component of the visit involved capturing photographs of mold-prone areas in residential buildings to validate the results collected through the interview. Participants were recruited through a door-to-door approach in Auckland, New Zealand, where homeowners were asked if they had experienced mold in their houses. These homes were selected based on their varying ages, construction materials, and ventilation systems levels to provide a representative understanding of mold-prone conditions. Only standalone houses were considered for this study. Participants were fully informed of the research purpose, and their written consent was obtained before data collection. Photographs did not include identifiable features. After capturing the pictures, participants were contacted via email to confirm the use of the images in the research. After capturing the photographs, the findings were compared with the interview results to validate the accuracy and consistency of the reported mold issues.

4.5 Results

4.5.1 Interview Findings

This section presents the experts' feedback on each learning objective (LO). A total of 12 experts (E1–E12) were consulted, and their responses were analyzed by counting how many supported or rejected each item. The questions focused on three main indoor environments: kitchen, bedroom, and bathroom.

To make the analysis consistent, a binary scoring system was used:

- 1 if an expert recommended the strategy
- 0 if they did not recommend it

The scores for each strategy ranged from 0 to 12, showing how many experts agreed. Based on the number of approvals, strategies were grouped into three categories:

1. Highly Recommended – 10 or more approvals

2. Moderately Recommended – 4 to 9 approvals
3. Less Recommended – 3 or fewer approvals

4.5.1.1 Mold Hotspots Identification (LO 1)

First, the interviewees were told about the aim of LO 1. Then, three slides were shown to them in which the highlighted hotspots were visible, including the correct and incorrect spots (Figure 4.14). The interviewees were asked to share their opinion regarding the highlighted correct hotspots. The interviewees agreed that certain spots in each room were more likely for mold to grow. In the kitchen, the windowsill was highlighted as a high-risk area. Similarly, the windowsill was identified as the most susceptible spot for mold in the bedroom. In the bathroom, the interviewees pointed out multiple regions, including the shower glass, around the shower or bathtub, grout and tiles, and behind the toilet, as the most likely locations for mold growth. Table 4.3 provides further details of interviewees' responses and recommendations.

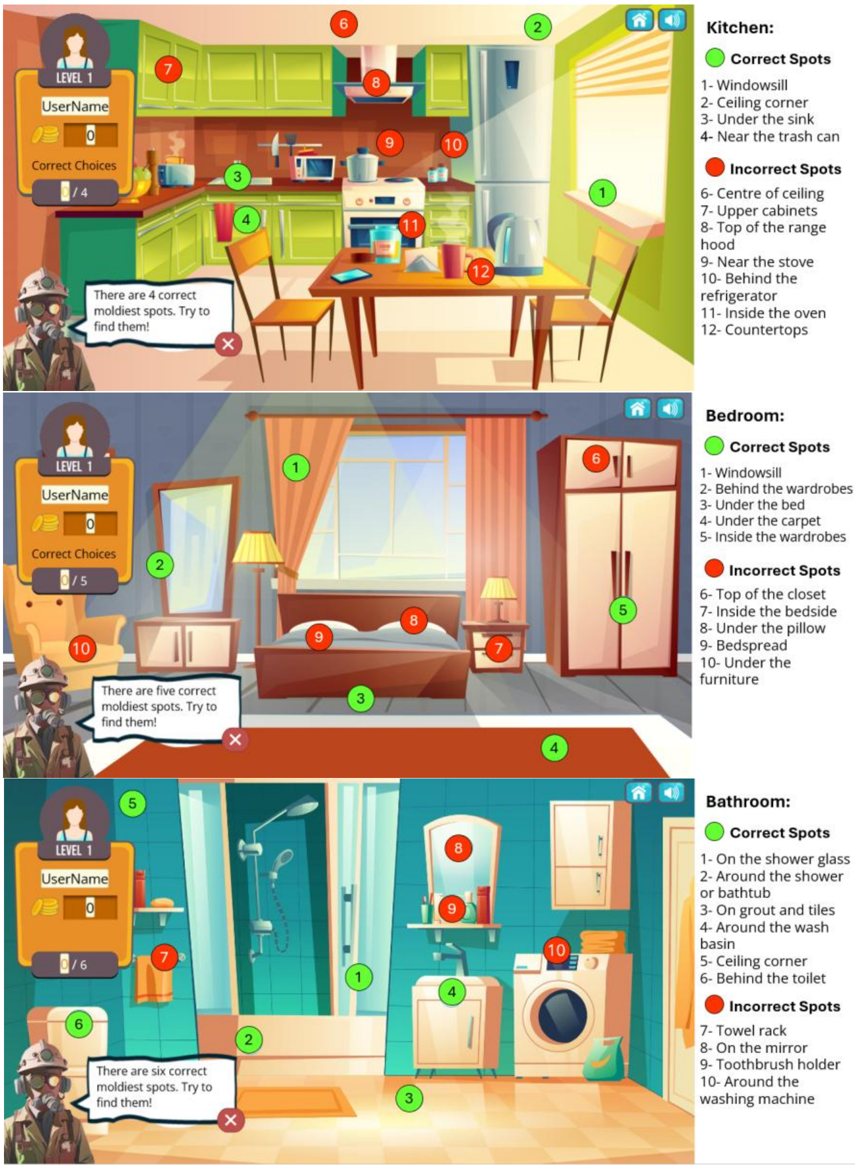


Figure 4.14: Sample slides were presented during the interview to gather expert input

Table 4.3: Common moldy spots in homes, according to the literature

Rooms	Spots	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
Kitchen	1- Windowsill	×	×	×	×	×	×	×	×	×	×	×	×
	2- Ceiling corner		×		×							×	
	3- Under the sink						×			×			
	4- Near the trash can					×						×	
Bedroom	1- Windowsill	×	×	×	×	×	×	×	×	×	×	×	×
	2- Behind the wardrobes		×	×	×					×			×
	3- Under the bed						×						
	4- Under the carpet				×								
	5- Inside the wardrobes	×	×	×		×			×		×	×	
Bathroom	1- On the shower glass	×	×	×	×	×	×	×	×	×	×	×	×
	2- Around the shower or bathtub	×	×	×	×	×	×	×	×	×	×	×	×
	3- On the grout and tiles	×	×	×	×	×	×	×	×	×	×	×	×
	4- Around the wash basin									×	×		
	5- Ceiling corner				×								
	6- Behind the toilet	×	×	×	×	×	×	×	×	×	×	×	×

Several participants highlighted specific locations as being particularly vulnerable to mold growth, often linked to moisture accumulation and poor air circulation. For example, one expert noted, *"Windowsill definitely… you could get it on the glass as well,"* while another explained, *"Ceiling corner — most likely to get mold there if there's insulation missing."* Hidden or less obvious areas were also mentioned, such as *"behind the dresser, especially if it's an old building,"* and *"behind the curtains,"* where condensation can accumulate. Bathroom areas were frequently cited, with one expert describing, *"If it's an old one, like a shower above the bath… definitely on grout and tiles, and around the wash basin."* Although some locations were considered less likely, such as *"inside the oven, definitely not"* or *"top of the washing machine, all pretty unlikely,"* the overall expert consensus emphasized that mold-prone areas are often those with poor ventilation, high humidity, or persistent dampness.

The interviewees expressed several opinions regarding mold risk and building design. They noted that areas under the sink are less likely to get moldy unless there are leaks or if they are located near the trash can. Additionally, they suggested including curtains as a potential factor in each room's mold prevention strategy. Seven interviewees recommended separating the laundry from the bathroom, proposing the development of a dedicated laundry room. Furthermore, they suggested incorporating windows into the bathroom since in the initial version of this room, there was no window. In kitchens, three interviewees suggested fruits inside the refrigerator or on countertops as potential mold-prone items. Ceiling corners, particularly those far from heat-producing appliances like refrigerators, were also often mentioned. This is because the heat from refrigerators helps prevent mold from growing near them. Curtains, particularly in bedrooms, were another commonly suggested mold-prone area, along with ceiling corners across all three rooms. Some interviewees noted that furniture near exterior walls, such as bed headboards, is susceptible to mold growth.

4.5.1.2 Key Factors of Mold Growth (LO 2)

For this learning objective, the discussion focused on the reasons for mold formation in homes within the New Zealand context and the current situation. Participants were presented with a list of key elements contributing to mold growth and asked whether any items should be added or removed. All participants agreed that humidity, temperature, nutrients, and spores are essential factors in mold formation. However, several experts raised concerns that the terminology might be too technical for a general audience. Most recommended replacing *"humidity"* with *"moisture"* and *"temperature"* with *"cold surface"* to improve clarity and accessibility. One participant also noted that including CO_2 and air pressure as "incorrect" options might confuse non-specialist users, as these concepts are less familiar to the public.

4.5.1.3 Environmental Conditions for Mold (LO 3)

For this learning objective, the discussion began with an overview of the temperature and humidity levels outlined in national standards and regulations for healthy indoor environments. Experts agreed that the optimal indoor temperature range should be between 18 °C and 22 °C, aligning with widely accepted comfort and health guidelines. Initially, the project team proposed an optimal relative humidity range of 35–55%. However, through the interviews, participants recommended revising this to 40–60%, explaining that keeping humidity consistently below 60% is often challenging, particularly in Auckland's humid climate. This adjustment reflects both practical experience in local housing conditions and the need to present learners with realistic, achievable targets for mold prevention.

4.5.1.4 Mold Prevention Strategies (LO 4)

The analysis revealed that four strategies (S2, S4, S6, and S15) were unanimously endorsed by all 12 experts, making them the most critical for mold prevention. These strategies include opening windows daily (S2), hanging washing outside to dry (S4), and using fans and rangehoods (S6). These strategies should be prioritized in awareness campaigns and intervention programs, given their universal acceptance. A second tier of strategies, including opening curtains during the day (S14), using a ventilation system (S8), leaving wardrobes slightly open (S13), venting dryers outside (S10), and pulling furniture away from walls (S12), received moderate agreement from 4 to 6 experts. These strategies may be beneficial in specific contexts, such as homes with limited natural ventilation or insulation issues. Finally, strategies with low endorsement ($\leqslant$3 experts), such as wiping condensation off windows (S1), limiting moisture sources (S7), and using dehumidifiers (S9), were less frequently recommended. These strategies may hold value but could be considered secondary measures or dependent on specific household conditions (Table 4.4).

Table 4.4: The strategies for mold prevention in homes

Strategies (Ss)	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**	**E12**
S1: Wipe condensation off windows and walls		×		×								×
S2: Open windows for 15 minutes every day	×	×	×	×	×	×	×	×	×	×	×	×

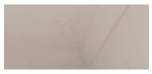
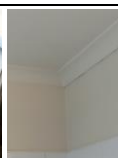
S3: Avoid using portable gas heaters/ unflued gas heaters			×				×					
S4: Hang washing outside to dry	×	×	×	×	×	×	×	×	×	×	×	×
S5: Use lids on pots when cooking	×	×		×						×		
S6: Use a rangehood in the kitchen	×	×	×	×	×	×	×	×	×	×	×	×
S7: Limit sources of moisture, such as fish tanks and indoor plants										×		
S8: Use the ventilation system	×		×				×		×			×
S9: Use dehumidifiers	×	×	×					×				
S10: Vent dryers outside		×	×	×	×	×	×					×
S11: Better heating and insulation of the house	×	×	×	×	×		×	×		×	×	×
S12: Pull beds and furniture away from the walls	×	×		×	×	×	×	×		×	×	
S13: Leave wardrobes a bit open	×			×	×	×					×	×
S14: Open the curtains during the day	×	×	×		×		×		×	×	×	×
S15: Use fans in the shower	×	×	×	×	×	×	×	×	×	×	×	×

As part of the final interview stage, the participants were also asked whether spaces beyond the kitchen, bedroom, and bathroom should be included in the game, such as lounges or garages. Most agreed that the current focus on these three spaces was appropriate, as areas like living rooms or garages are often too generic. Lastly, participants were asked whether developing only bedrooms and bathrooms to apply the strategies would benefit users. Universally, participants endorsed this approach, emphasizing the critical importance of bathrooms as one of the most mold-vulnerable home spaces.

4.5.2 Home Visit Findings

This section presents an overview of the key specifications of the investigated homes, focusing on mold presence in different areas and its correlation with construction type, house age, and location. As part of this research, six standalone homes across New Zealand were investigated to assess mold growth in different areas of residential buildings, each exhibiting varying degrees of mold contamination. Notably, mold was observed in kitchens, bathrooms, and bedrooms, with severity depending on structural characteristics and ventilation conditions. Table 4.5 provides further specifications of the homes investigated.

Table 4.5: Summarizing the key specifications of the investigated homes

Home ID	Location	Housing Type	House Age (Years)	Construction Type	Mold Presence	Spot(s)	Pictures
H1	Takapuna, Auckland	Standalone house	25	Timber-Framed	Kitchen	Windowsill and frames	
H2	Mount Eden, Auckland	Standalone house	20	Brick	Kitchen	Windowsill and frames	
H3	Northcote, Auckland	Townhouse	15	Timber-Framed	Bathroom	Around the wash basin	
H4	Albany, Auckland	Standalone house	20	Concrete Block	Bathroom	All over the ceiling and the inner side of the walls	 
H5	Albany, Auckland	Standalone house	30	Timber-Framed	Bedroom and Bathroom	Behind the dresser/closet and all over the ceiling	 
H6	Albany, Auckland	Townhouse	22	Timber-Framed	Bedroom and Bathroom	Window frames, the inner side of the walls, all over the ceiling, on grout and tiles, and the	   

						inner side of the walls	

The findings indicate that bathrooms are the most vulnerable areas for mold growth due to their constant exposure to moisture, steam, and often limited ventilation. On the other hand, kitchens generally exhibit lower mold presence. In bedrooms, mold is frequently observed in areas with poor insulation or heating, particularly on window surfaces and cold exterior walls where condensation accumulates. Some homes (e.g., H4, H5, H6) showed extensive mold growth across large surfaces, particularly in bathrooms, where moisture levels remain consistently high. In H4, mold covered the entire walls and ceiling, indicating severe humidity issues.

4.5.3 Finalized Version of the Learning Objectives

The verification results provided valuable insights that directly shaped the serious game's design, features, and learning objectives. The finalized version of LOs incorporates several changes based on the verification results. Further details are provided in Table 4.6 and Table 4.7. The bathroom scene was also modified to show the overall ceiling, incorporating a window, based on experts' opinions (Figure 4.15).

Table 4.6: The final selected moldy spots compared with the literature

Rooms	Literature	Verification results (finalized)
Kitchen	1- Windowsill 2- Ceiling corner 3- Under the sink 4- Near the trash can	1- Windowsill and frames 2- On the curtains 3- In the cabinets 4- Around the trash can
Bedroom	1- Windowsill 2- Behind the wardrobes 3- Under the bed 4- Under the carpet 5- Inside the wardrobes	1- Windowsill and frames 2- On the curtains 3- Inside the wardrobes 4- Behind the wardrobes 5- Behind the dresser
Bathroom	1- On the shower glass 2- Around the shower or bathtub 3- On the grout and tiles 4- Around the wash basin 5- Ceiling corner	1- Windowsill and frames 2- On the curtains 3- Ceiling corner 4- All over the ceiling 5- On the shower glass

	6- Behind the toilet	6- Around the shower or bathtub 7- on the grout and tiles

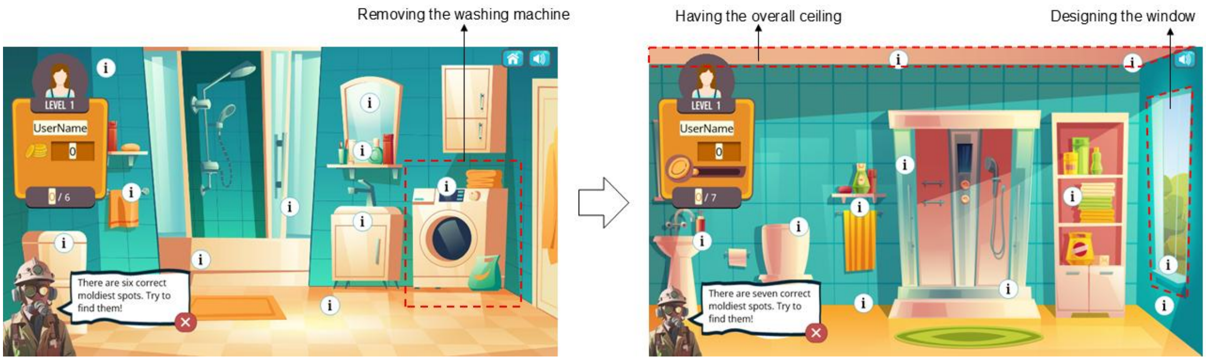


Figure 4.15: Comparison between the initial version of the scene and the updated version

The findings reflect experts' suggestions with adjustments to recommended temperature and humidity ranges. Specifically, the temperature was changed to 20–24°C, rather than the earlier suggested 18–22°C, to maintain a warmer indoor environment and prevent condensation. Similarly, the humidity range was adjusted to 40–60%, rather than 35–55%, based on expert recommendations. Also, the game emphasizes practical strategies to prevent mold growth, including opening windows for at least 15 minutes every day, hanging laundry outside to dry, using a rangehood in the kitchen, venting dryers outside, improving heating and insulation, pulling beds and furniture away from walls, leaving wardrobes slightly open, opening curtains during the day, and using fans in the shower. These strategies were selected based on expert recommendations (Table 4.7).

Table 4.7: The final strategies according to the experts' feedback

Literature (initial version)	Experts' opinion (refined version)

• Wipe condensation off windows and walls. • Open windows for 15 minutes every day. • Avoid using portable gas heaters/ unflued gas heaters. • Hang washing outside to dry. • Use lids on pots when cooking. • Use a rangehood in the kitchen. • Limit sources of moisture, such as fish tanks and indoor plants. • Use a ventilation system. • Use dehumidifiers. • Vent dryers outside. • Better heating and insulation of the house. • Pull beds and furniture away from walls. • Leave wardrobes a bit open. • Open the curtains during the day. • Use fans in the shower.	• Open windows for 15 minutes every day. • Hang washing outside to dry. • Use a rangehood in the kitchen. • Vent dryers outside. • Better heating and insulation of the house. • Pull beds and furniture away from walls. • Leave wardrobes a bit open. • Open the curtains during the day. • Use fans in the shower.

Consequently, the validation process confirmed that the game content accurately reflects real-world experiences. Expert feedback highlighted actionable strategies, such as briefly opening windows each day or venting dryers to the outside, which have been incorporated into the game. This ensures the content is theoretical and firmly rooted in everyday practicality.

4.6 Discussion

The main objectives of this study are, first, to develop a prototype of a serious game aimed at educating individuals on preventing mold growth in residential buildings, and second, to verify the educational content of the game. To achieve this, a detailed step-by-step development process was outlined. Educational content was gathered through multiple stages, including reviewing reliable websites and national building codes in New Zealand, conducting semi-structured interviews with experts, and performing home-visit investigations to provide solid evidence of mold-prone areas. The findings of this study highlight the need to prioritize mold prevention strategies for specific areas in residential buildings based on their unique environmental conditions. Bathrooms emerged as the most critical spaces due to their high humidity, frequent water exposure, and often limited ventilation. Bedrooms, however, pose distinct challenges, with condensation on windows, cold walls, and poor ventilation contributing to mold growth, particularly in homes with inadequate insulation or heating.

While previous studies (J. Fernandes et al., 2023; Kim et al., 2021; Kim & Sohanchyk, 2022; S. Kim et al., 2022; Shabanabegum et al., 2021) have focused on general air pollution education, this research uniquely integrates hands-on strategies for mold prevention, bridging a critical gap in the existing literature. A comparison between the game mechanics selected in this study and those identified in previous research focused on IAQ reveals both similarities and key differences. For example, Pokric et al. (2015) used mechanics such as points, leaderboards, and avatars to educate professional employees about air pollution and its effects on human health. Other mechanics included narrative, level progression (LevelUp), quest lists, step-by-step tutorials, instant feedback, progress bars, avatar customization, progress loss, and a visual storyline. Positive feedback highlighted the simplicity of the augmented reality development, usability, and available features, while the game was also deemed entertaining. However, feedback indicated the need for additional tutorials to enhance user engagement.

Also, J. Fernandes et al. (2023) utilized similar mechanics, such as narratives, quest lists, step-by-step tutorials, points, instant feedback, and group quests, to improve IAQ knowledge among elementary school children. Their results showed a 50% improvement in knowledge. Satisfaction, usability, and user preferences were also assessed through questionnaires, although technical issues related to AR implementation, particularly with marker tracking, were reported. Relvas (2021) employed mechanics such as narratives, quest lists, step-by-step tutorials, and visual storytelling to raise awareness about air pollution and help elementary students understand its possible causes. This comparison suggests that building on the mechanics used in previous studies could lead to positive outcomes. The post-assessment results indicated a significant improvement in the children's perception of air pollution, highlighting the effectiveness of these game mechanics in enhancing learning and awareness.

Several studies have focused on the usability and engagement of gamification applications. For instance, Alarcon et al. (2025) evaluated a serious game designed for teacher training in environmental sustainability. The study used the System Usability Scale to assess the platform's user-friendliness. Results showed a moderate SUS usability score, indicating acceptable levels of ease of use. Importantly, participants reported that gamification elements, such as feedback and reward mechanisms, significantly enhanced their motivation and engagement and supported competency development in scientific inquiry. Nadeem et al. (2023) evaluated a game-based quiz embedded in undergraduate courses using leaderboard mechanics. They found that digital game-based learning significantly boosted student engagement and motivation compared to traditional online quizzes. This demonstrates that thoughtfully designed digital quizzes can meaningfully enhance usability and engagement in higher-education learning environments.

Kayyali et al. (2021) investigated a digital serious game integrated into healthcare education, focused on playability and user perceptions. Participants praised the game's clear learning objectives, intuitive interface, and story-driven progression, all of which contributed to sustained engagement during practical use. These findings highlight that, beyond core usability, narrative structure and straightforward task design are essential for maintaining user focus and instructional efficacy. Similarly, Espinosa-Curiel et al. (2020) developed a nutrition-focused video game for children aged 8–10 years. Their findings revealed a strong link between usability factors (challenge, narrative, visual aesthetics) and learning outcomes. They also found that enjoyment and user-experience satisfaction positively correlated with posttest knowledge. Regression analysis confirmed these usability dimensions as significant predictors of knowledge gain.

Contrary to concerns about over-gamification, recent literature suggests that multiple, well-integrated mechanics can coexist without undermining usability. Magylaitė et al. (2022) synthesized findings from over 100 gamified systems and identified that combining mechanics like progress indicators, feedback, and rewards, when designed with learnability in mind, maintains usability and enhances engagement. Likewise, Ghai and Tandon (2023) used structural equation modelling to show that the interplay of game elements, dynamics, and instructional design measurably improves usability in e-learning systems. Lassaad and Yamani (2024) demonstrated a 25% increase in engagement and 30% improvement in motivation/performance from using points, badges, leaderboards, and challenges, with no usability detriment.

4.7 Conclusion

This study explored the development and evaluation of a serious game aimed at enhancing public knowledge on mold prevention in residential settings. The game was designed using a structured framework aligned with Bloom's Taxonomy and evidence-based mold prevention strategies. Through a single-arm experimental design, results indicated that the serious game significantly improved participants' knowledge across various mold-related domains. The integration of gamified elements such as immediate feedback, reward systems, and interactive challenges contributed to learner engagement and knowledge acquisition. Overall, the findings support the potential of serious games as effective tools for environmental health education and behavioral change in the built environment. This study has some limitations. First, the verification step overlooked gameplay and game mechanisms, since only IAQ experts were involved in interviews to examine educational content. Second, this study does not include a verification step to assess the effectiveness and user experience of the game.

This game can be scaled by deploying it as a lightweight HTML5 package with SCORM/xAPI integration, allowing delivery through learning management systems or public web hosting for access across devices. Its modular design, with externalized text and audio, enables rapid localization, cultural adaptation, and the addition of new modules or learning scenarios. Distribution through public health, education, and professional training channels, supported by integrated analytics, allows expansion from small pilots to large-scale national or international use. Language translation and localization enable the game to reach a broader audience and adapt to diverse cultural contexts, with broader implications for public health education in the built environment sector by raising awareness of healthy housing practices, influencing behavior change, and supporting evidence-based interventions at scale. Future studies could incorporate pretest-posttest controlled experiments to investigate its effects on knowledge acquisition and compare it with other conventional education methods.

Further studies could also investigate the long-term impact of behavioral change and implementation of mold prevention practices in real life. Other educational technologies, including the Internet of Things and Augmented Reality/Virtual Reality, or integration of these tools, could be explored to provide real-time, interactive information within a physical space, offering a customized learning experience for health-related applications in the built environment. Future research should investigate the effectiveness of the game across multiple dimensions, including knowledge acquisition, motivation, system usability, self-efficacy, task load, behavioral change, and long-term knowledge retention.

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Student name:	Abdollah Baghaei Daemei
Name and title of main supervisor:	Dr Zhenan Feng
In which chapter is the manuscript/published work?	Chapter 5

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Abdollah Baghaei Daemei: Writing – review & editing, Writing original draft, Visualization, Resources, Methodology, Investigation, Conceptualization. Zhenan Feng: Writing – review & editing, Supervision, Methodology, Conceptualization. Daniel Paes: Writing – review & editing, Supervision, Conceptualization.

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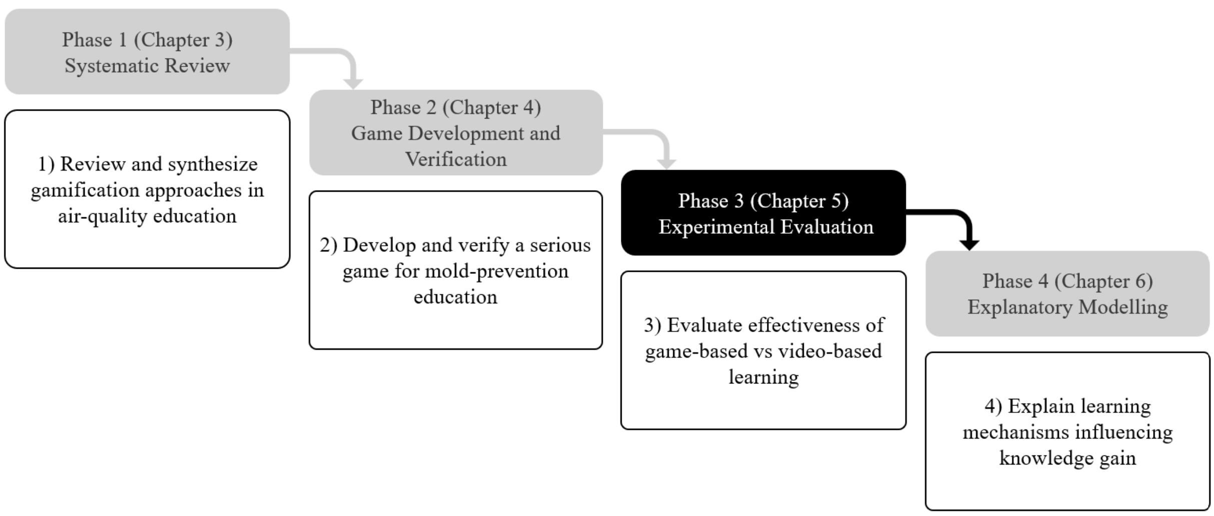
Chapter 5

Serious Game Evaluation

This chapter is based on the following Journal article, which is under review:

Baghaei Daemei, A., Feng, Z., Paes, D., (2025). A Serious Game for Mold Prevention Education: A Comparative Study with Video-based Learning, Journal of Computer Assisted Learning, Under review (R2).

Following the development and verification of the serious game described in Chapter 4, this chapter (Chapter 5) evaluates the effectiveness of the game-based learning compared with video-based learning approach. Whereas the previous chapter focused on design and content validation, the present chapter examines knowledge, knowledge retention, task load, user experience, motivation, self-efficacy, and behavior change through controlled experimental testing.



Chapter 5: Serious Game Evaluation

5.1 Introduction

IAQ is a critical determinant of human health and well-being, particularly within residential environments. Among the various contributors to poor IAQ, mold contamination is one of the most pervasive and harmful, thriving in damp and inadequately ventilated spaces (Heseltine & Rosen, 2009). Exposure to mold has been linked to a wide range of adverse health effects, including respiratory problems, allergic reactions, and the exacerbation of asthma symptoms, especially among vulnerable populations such as children, the elderly, and individuals with pre-existing conditions (Hao et al., 2024; WHO, 2019). These concerns are not confined to any one region, they represent a growing global public health issue. Around the world, ageing housing stock, poor ventilation, and inadequate moisture control contribute to widespread mold contamination in residential buildings.

In many countries, particularly across Europe and North America, outdated construction practices and energy-inefficient homes have led to persistent dampness and poor air circulation. For example, a pan-European study reported that approximately 12% of households experience mold-related issues, with vulnerable populations such as low-income families and children disproportionately affected (WHO, 2023). In the United States, the Centers for Disease Control and Prevention have acknowledged indoor mold as a significant health concern, especially in flood-prone regions where sustained moisture creates ideal conditions for fungal growth. Similar challenges are also reported in parts of Asia, South America, and Oceania, where climatic factors, overcrowding, and limited public awareness further exacerbate the risks. Collectively, these patterns reflect the urgent need for scalable, effective educational interventions to address indoor mold exposure worldwide.

Recent research highlights that pollution levels indoors can exceed those found outdoors, even in densely populated urban areas (IQAir, 2018; MANA, n.d.; Sanalife, 2022). Kankaria et al. (2014) reported that the impact of indoor air pollution can be up to ten times more severe than that of outdoor pollution. Given that individuals spend approximately 90% of their time indoors, the potential health risks associated with indoor pollutants are significantly magnified (Tran et al., 2020). According to the WHO (2023), "*Each year, 3.2 million people die prematurely from illnesses attributable to household air pollution. Particulate matter and other pollutants in household air inflame the airways and lungs, impair immune response, and reduce the oxygen-carrying capacity of the blood*."

These global concerns are acutely relevant to New Zealand, where mold-related problems are particularly prevalent (Environmental Health Intelligence, 2025). According to a 2015 BRANZ survey highlighted in Consumer (2023), more than half of rental homes in New Zealand had visible mold, often caused by persistent moisture issues that are difficult for tenants to control. Keall et al. (2012) also found that such conditions were associated with increased rates of wheezing and asthma. Cold and damp housing environments contribute to higher seasonal mortality rates and increased incidences of cardiovascular and respiratory illnesses. In 2018, approximately 28,000 New Zealand homes were reported to be persistently damp and to have visible mold larger than A4 size (StatsNZ, 2020). Thus, addressing mold-related issues in New Zealand housing is both urgent and necessary. A substantial body of research has established the link between poor IAQ and adverse health outcomes in mold-affected dwellings (Graham, 2023; Lewis et al., 2023; Morawska et al., 2024; Nature Editorial, 2023; Stokstad, 2004).

Addressing these challenges requires not only technical solutions but also effective educational strategies to raise awareness and promote sustainable behavioral change (Freeman et al., 2014). While traditional methods (e.g., brochures and instructional videos have been widely used to convey health messages, they often lack the interactivity and engagement needed to maintain attention, foster motivation, and support long-term knowledge retention (Mayer, 2017).

Educating individuals about such issues is paramount due to their significant and far-reaching implications on public health and the environment (Marcotte, 2017). If people become more aware of the importance of air pollution, it is more likely to prompt positive changes in both individual behavior and public policies (Kelly & Fussell, 2015). This increased awareness has the potential to drive actions to mitigate pollution, resulting in a cleaner environment and a healthier population (Arcury, 1990; Wang et al., 2016). Many people are unaware of the invisible threats in the air we breathe, and raising awareness is crucial for informed decision-making and behavior (Barbosa et al., 2017).

Serious games provide an alternative approach by transforming passive learning into an active and immersive experience (Checa & Bustillo, 2020). These games simulate real-world scenarios, enabling learners to apply knowledge in meaningful and contextually relevant ways. An innovative and alternative approach gaining momentum is the incorporation of gamification into air quality education. Gamification transforms learning about air quality into an engaging and interactive experience by applying game elements and offering various features such as real-time data collection (Polychronidou et al., 2019). Through gamified applications and platforms, individuals can participate in challenges, quizzes, and simulations that simulate real-world scenarios related to air quality (Stamatiadou et al., 2023).

The use of gamification has been explored in many fields. For example, it has been successfully applied to training in areas such as earthquake preparedness (Çoban & Göktaş, 2023; Feng et al., 2021; Mirsoleymani et al., 2022), safety procedures (Kazar & Comu, 2021; Lovreglio et al., 2021), construction site awareness (Lu et al.; Tagliabue et al., 2020), hazard detection (Cavalcanti et al., 2021; Mohd et al., 2019; Ren et al., 2022), and risk management (Taillandier & Adam, 2018), as well as broader topics in the built environment (Ilbeigi et al., 2024; Lai et al., 2020; Villagrasa et al., 2014).

Prior comparative research demonstrates that serious games typically produce small-to-moderate gains in learning ($g \approx 0.29$–0.36) and motivation ($g \approx 0.34$–0.48) relative to conventional instruction (Sailer & Homner, 2020; Wouters, Nimwegen, et al., 2013). In health and medical education, serious games and gamified approaches are often at least as effective as standard teaching, and in many cases more effective, although findings are not uniform across all outcomes and designs (Gentry et al., 2019). However, these studies have predominantly focused on disciplines such as medicine, nursing, and STEM education and have not directly addressed IAQ or residential mold education. Furthermore, much of the existing comparative research emphasizes immediate post-learning outcomes rather than long-term knowledge retention or real-world behavioral transfer, which are critical for sustained environmental health practices (Maheu-Cadotte et al., 2018).

A recent systematic literature review conducted by Abdollah Baghaei Daemei et al. (2025) examining gamification in air quality education identified serious game applications in domains such as general air pollution awareness, environmental sustainability, and health education, but found minimal attention to residential mold prevention as a specific instructional target. This confirms that mold-prevention education remains an underexplored area within serious game–based environmental health interventions. This highlights a significant domain-specific gap: while air-quality gamification has been used to raise awareness (Campana & Dominguez, 2021; João Fernandes et al., 2023) and support asthma management (Sunyoung Kim et al., 2022; Thomson et al., 2017), no existing work supports actionable mold-prevention knowledge or real-world behavioral transfer in residential contexts.

As such, this study aims to address this gap by developing and evaluating the effectiveness of a serious game compared to video-based learning aimed at educating the general public on mold prevention techniques in residential settings. The evaluation focuses on key learning performance metrics, including knowledge acquisition and retention, cognitive task load, system usability, intrinsic motivation, and self-efficacy. This research contributes to the growing body of knowledge on educational strategies in the built environment. In doing so, this study expands the limited research on serious games for mold prevention and informs practical, scalable educational strategies for addressing poor indoor air quality in residential environments. Ultimately, it contributes to a healthier and more resilient built environment.

Many serious games are built on established instructional and motivational design frameworks, including LM–GM mapping (Arnab et al., 2015), the RETAIN model (Gunter et al., 2008), and the MDA framework (Hunicke et al., 2004). Meta-analyses also show that game-based learning outcomes are frequently linked to constructs from Self-Determination Theory, the ARCS model, and related theories (Krath et al., 2021; Richard N. Landers, 2014; Sailer & Homner, 2020). At the same time, the degree of theoretical alignment across the broader field remains uneven, with many applications offering limited explanation of how specific mechanics connect to learning objectives or behavioral processes. Education in the built environment, including IAQ and mold prevention, presents an even larger gap: very few studies integrate structured design models with the behavioral and perceptual demands of identifying mold risks and adopting effective moisture-management habits. This gap establishes the need for a theory-informed approach tailored to mold-prevention education.

This study theorizes that mold-prevention education poses unique instructional demands that differ from other health and safety domains. Mold risk is shaped by micro-level household actions that directly modify the indoor environment, such as ventilation practices, moisture-generating activities, surface exposure, and material choices. These actions alter airflow, surface temperature, and humidity conditions, which require situated spatial reasoning rather than declarative recall. The game was therefore intentionally designed with interactive spatial environments that allow learners to test environmental modifications and observe their effects through immediate feedback. This alignment between instructional modality and domain-specific learning requirements represents a theoretical rationale underlying the study design.

5.2 Materials and Methods

This study investigates the effectiveness of a serious game in enhancing knowledge related to mold prevention in residential buildings compared with video-based learning. The overall research workflow is illustrated in Figure 5.1. This study followed a structured multi-stage development and evaluation process. First, we defined the conceptual requirements of the intervention (Step 1) and collected relevant educational content on mold prevention in homes (Step 2). The materials were refined through interviews and in-home assessments to ensure practical relevance (Step 3), followed by prototyping of both the game and the video-based learning module (Step 4). Next, we developed the experimental design and questionnaires (Step 5), recruited participants (Step 6), and conducted the experiment and data collection (Step 7).

Finally, collected data were analyzed to assess the intervention's impact (Step 8). Each development step underwent iterative internal review and debugging, informing refinement across stages.

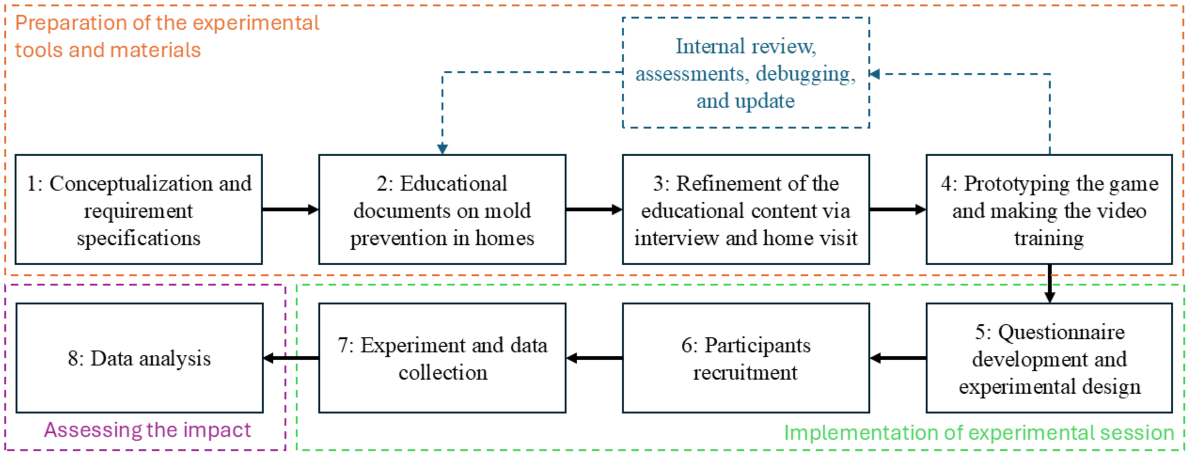


Figure 5.1: Research process workflow

5.2.1 Game Development

This study presents a serious game prototype designed to educate individuals on mold growth prevention in residential buildings. The game aims to engage users in identifying mold-prone areas, understanding the conditions conducive to mold formation, and applying practical strategies to prevent mold growth. The game was developed using Storyline 360 (www.articulate.com/360/storyline), which provides an easy-to-use design interface and supports the creation of interactive elements such as triggers, clickable areas, and dynamic feedback. It is designed to be accessible on various platforms, including PCs, laptops, tablets, and smartphones, ensuring that users from diverse backgrounds can engage with the content independently. The target audience for this serious game comprised the general public across New Zealand, including homeowners, renters, and individuals living in diverse housing conditions. This is supported by several studies reporting that more than half of New Zealand rental houses had visible mold (BRANZ, 2015; Consumer, 2023). The game was developed using New Zealand housing and climate conditions as an initial case-study context. The educational content can be substituted or expanded to suit other regions and housing typologies. This structure allows the intervention to be adapted for international use with minimal reconfiguration of the underlying system.

5.2.1.1 Learning Outcomes

The game has four learning objectives (LOs) designed based on Bloom's Taxonomy (Krathwohl, 2002), focusing on three cognitive levels: remember, understand, and apply. This framework ensures a structured progression of learning, guiding players from basic knowledge acquisition to practical application in real-life scenarios. The LOs are presented as follows:

- Remember (LO1 & LO2): This module involves recalling facts and recognizing key information. LO1 requires players to identify specific spots in the kitchen, bedroom, and bathroom where mold is likely to grow, reinforcing memory-based recognition of mold-prone areas. Similarly, LO2 focuses on recalling the essential elements of mold formation helping players establish foundational knowledge of mold growth conditions.
- Understand (LO3): This module emphasizes comprehension and the ability to explain concepts. LO3 requires players to understand how specific environmental conditions, such as temperature and humidity, contribute to mold growth. This goes beyond memorization by enabling players to connect different factors and predict when and where mold is likely to develop.
- Apply (LO4): This module involves using acquired knowledge in real-world contexts. LO4 focuses on applying strategies to prevent mold growth in residential buildings. This requires players to take what they have learned about mold-prone areas, essential growth factors, and environmental conditions, and translate that knowledge into actionable steps for maintaining a healthier indoor environment.

The learning outcomes and educational content were developed based on official public sources, including relevant governmental regulations, standards, building codes, and international publications (Abdollah Baghaei Daemei, Zhenan Feng, et al., 2025). This provided evidence-based knowledge rather than general assumptions. The game had four modules to accommodate the four learning outcomes (Figure 5.2). Players completed the entire learning process by playing the game from Module 1 to Module 4.

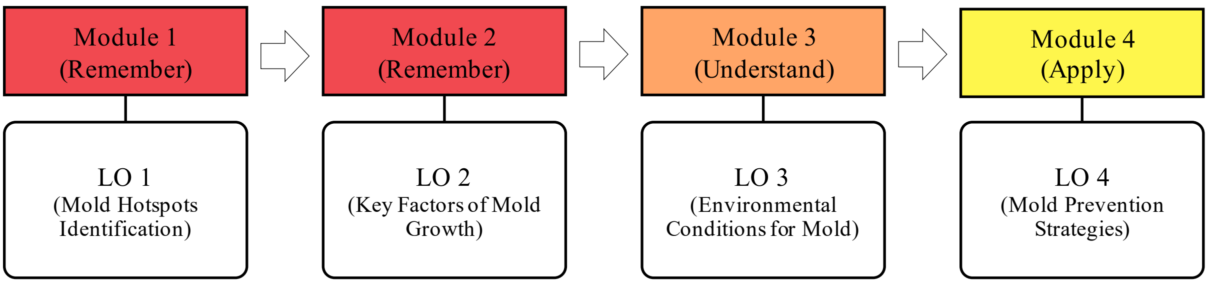


Figure 5.2: The learning outcomes and game modules

5.2.1.2 Game Mechanics

The Octalysis Gamification Design Theory principles (Chou, 2015) were applied in the development of the game to enhance engagement and motivation. This theory proposes game mechanics aligned with intrinsic and extrinsic motivators, which can engage and motivate players while delivering educational content. Chou (2015, p. 31) provides eight core drives (CDs) and associated game mechanics to engage and motivate players in different ways. Table 5.1 presents the selected game mechanics for the serious game.

Table 5.1: The selected game mechanics incorporated into the game

Core Drives (CDs)	**Mechanics**	**In-Game Application**	**Explanation/Usage**
CD 1: Meaning	Narrative	Story-driven progression through house rooms	Narrative refers to the storyline and context that immerse players in the learning experience. It integrates characters, scenarios, and challenges that provide a real-world framework for players to explore through a compelling story.
	Higher Meaning	Learners believe their actions affect real health	It provides players with a sense of purpose beyond the game itself. Players are motivated not just by the game's rewards, but by the belief that their actions contribute to a greater cause or have real-world significance.
CD 2: Accomplishment	Points	Player gains points for correct answers	Points are extrinsic rewards that recognize players' actions and achievements.
	Progress Bar	Shows completion of each module	The progress bar visually represents how far the player has come in completing a task or mission.
	Quest Lists	Tasks guide exploration	Quest lists outline tasks or challenges that guide the player's journey.

	Step-by-Step Tutorial	Explanation before each module	The tutorial breaks down tasks and teaches the player how to succeed in the game.
	LevelUp Symphony	Unlocking next module	Whenever you level up, you acquire a new set of skills.
CD 3: Empowerment	Milestone Unlock	After completing a task (e.g., identifying all condensation hotspots), the next module or tool becomes available	It represents a key achievement or significant event in the game that rewards the player with new content and levels. It marks the completion of a specific set of tasks.
	Instant Feedback	Immediate reinforcement	The immediate responses players receive based on their actions or decisions in the game.
CD 4: Ownership	Avatar	Personalized the gameplay	A customizable digital representation of the player within the game.
CD 5: Social Influence	Mentorship	Virtual assistant guidance	It refers to a guidance system where an experienced character (a virtual character) provides the player with advice, support, and knowledge.
CD 7: Unpredictability	Visual Storytelling	When a player completes a module, a brief animation and confirmation cue appear	This mechanic uses images, animations, and design elements to convey the game's narrative and themes. Rather than relying on text or dialogue, it communicates key messages, emotions, and ideas through art style, character design, environments, and visual cues.
CD 8: Avoidance	Progress Loss	Penalty for wrong responses	It refers to the mechanic where players lose some in-game points after failing the task or challenge.

5.2.1.3 Game Storyline

The detailed design and narrative development of the serious game have been presented comprehensively in Chapter 4 of this thesis. Readers seeking a full description of the game architecture, narrative structure, and design rationale are referred to Chapter 4, where the development process and pedagogical alignment of the storyline are discussed in detail.

5.2.2 Experimental Design

This study adopted a between-subjects experimental design, where each participant was exposed to only one of the two learning methods (game or video). Figure 5.3 illustrates the experimental design framework, including the research instruments and variables. This approach was chosen to prevent learning effects that could occur in a within-subjects design, where participants would experience both conditions. In such cases, performance in the second condition could be influenced by prior exposure to the first, thereby biasing the results (Paes et al., 2024).

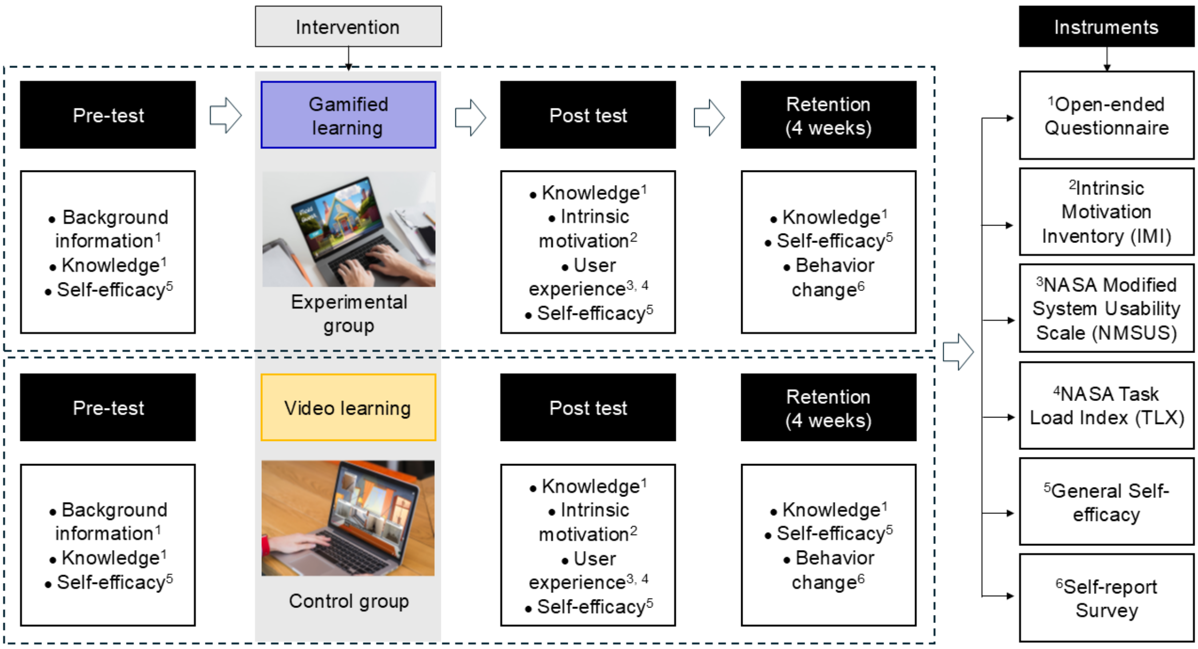


Figure 5.3: The experimental design framework

Participants were randomly assigned to one of the two groups, with one using the serious game as the experimental group and the other as the control group using video learning. Both methods comprised identical learning outcomes and educational content. The same images used in the serious game were incorporated into the video to maintain visual consistency (Figure 5.4). The video was structured with four main sections: (1) common mold growth spots, (2) key elements required for mold development, (3) optimal temperature and humidity ranges to prevent mold growth, and (4) effective strategies for mold prevention. The narration in the video used the same voice as the one featured in the game, maintaining uniformity in tone and delivery. Participants were permitted to pause the video at any time; however, they were not allowed to take notes, and the rewind function was restricted to only one slide back.

Figure 5.4: Screenshots of the video

Video-based learning was selected as the comparison condition because it represents one of the most commonly used digital formats for public-health communication (Chatterjee et al., 2021). Unlike brochures or flyers, videos can deliver structured explanations, visuals, and demonstrations that closely match the content density and pacing of the game (Galmarini et al., 2024; Morgado et al., 2024). This makes video a more appropriate benchmark for isolating the role of interactivity, since both modalities present the same information but differ in the level of learner engagement.

Each group went through a pretest, intervention, posttest, and retention test. The retention test occurred four weeks after the posttest, aligning with previous similar studies (Domgue K et al., 2025; Paes et al., 2024). Participants were provided with a laptop in the lab to complete the pretest, learning, and posttest. Each session took around 30 minutes for the game group and 20 minutes for the video group. Participants completed the online retention test four weeks later using their own device.

The video used in the comparison condition presented the same educational content as the game, refined into a continuous 5-minute narrated explanation of mold-prevention concepts without interactive elements. Participants completed the pre-test and post-test questionnaires in approximately 15 minutes, and the retention questionnaire required about 5 minutes. To link pre-, post-, and retention data, each participant was assigned a unique anonymous identifier. Email addresses were used solely to distribute the retention questionnaire and were stored separately from response data. No personal or demographic information was collected, and all procedures adhered to institutional ethical approval and data-protection requirements. The pre-test and post-test knowledge assessments consisted of the same set of questions, presented in the same order and format, to allow for direct comparison of learning gains.

The independent variable in this study was the intervention method, with the game and video as the two conditions. The dependent variables included knowledge measured with an open-ended questionnaire, self-efficacy measured using the General Self-Efficacy (GSE), intrinsic motivation measured with the Intrinsic Motivation Inventory (IMI), user experience measured through the NASA Task Load Index (TLX) and the NASA Modified System Usability Scale (NMSUS), and behavioral change assessed through a questionnaire on implemented mold prevention strategies. As demonstrated in Figure 8, knowledge and self-efficacy were measured in the pretest, posttest, and retention test; motivation and user experience were measured in posttest; and behavioral change was measured in the retention test. In addition, participant demographic information was collected in the pretest.

5.2.3 Data Collection Instruments

5.2.3.1 Demographics

This part gathered information including age, gender, type of residential housing, and frequency of playing video games. This data was used to contextualize participant characteristics and ensure consistency among participant profiles between the two groups.

5.2.3.2 Knowledge

An open-ended questionnaire was used to assess participants' knowledge to identify mold-prone areas, understand the essential conditions for mold growth, recognize temperature and humidity ranges to prevent mold growth, and apply prevention strategies. Participants' responses were manually scored. For the first module, correct answers included four spots in the kitchen, five spots in the bedroom and six spots in the bathroom. Participants obtained 1 score for each correct spot mentioned in their responses. For the second module, correct answers included four key elements: moisture, cold surface, nutrients, and spores. Participants obtained 1 score for each correct item mentioned in their responses. For the third module, correct answers included two items, including temperature (20-24°C) and humidity (40-60%). For the fourth module, the correct answers included nine mold prevention strategies. As a result, a participant could score between 0 to 30 points in total for the four modules. The same scoring method was applied for the pre-test, post-test, and retention test.

5.2.3.3 Intrinsic Motivation

In this study, a customized version of the Intrinsic Motivation Inventory (IMI) (Choi et al., 2010) was used to assess the intrinsic motivation of participants during their learning process. IMI is grounded in the Self-Determination Theory (SDT) and is commonly used to evaluate how enjoyable, interesting, and engaging participants found the material, as well as their level of focus, relaxation, and enjoyment during the learning experience (Ryan & Deci, 2020). Based on the standard IMI framework developed by Deci and Ryan (2013), three subscales were selected for their relevance to the study context: interest/enjoyment, perceived competence, and pressure/tension. Each subscale featured three items. Each item was rated using a 7-point Likert-type scale, ranging from 1 (strongly disagree) to 7 (strongly agree). For each participant, scores for each subscale were calculated by averaging the scores of the relevant items. Higher scores indicated higher levels of intrinsic motivation.

5.2.3.4 System Usability Scale

The NASA Modified System Usability Scale (NMSUS) (NASA, 2023) was employed to evaluate the usability of the learning tools (game or video). This scale provides insights into how user-friendly the learning tools were and whether technical support was needed for efficient use. Each item was rated using a 7-point Likert-type scale, ranging from 1 (strongly disagree) to 7 (strongly agree). For each participant, their NMSUS score was averaged from eight items. Higher scores indicated higher perceived usability levels.

5.2.3.5 Task Load Index

The NASA Task Load Index (TLX) (Hart, 2006) was used to measure the perceived task load during the learning experience for both game and video groups. The tool is particularly popular in human-computer interaction, usability research, aviation, healthcare, and education contexts (Kosch et al., 2023). The NASA TLX consists of six dimensions of subjective task load, including: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Each dimension featured one item and was rated by participants on a Likert-type scale ranging from 0 to 20, where 0 indicated very low and 20 indicated very high task load.

5.2.3.6 Self-Efficacy

The General Self-Efficacy Scale (GSE) (Luszczynska et al., 2005) was used to evaluate participants' self-perceived capability to handle challenges related to mold prevention, ranging from general confidence to specific actions, such as identifying solutions and applying preventive strategies. In this study, the GSE was administered using a 7-point Likert-type scale, with response options ranging from 1 (completely false) to 7 (completely true). The scale consists of five items. The overall self-efficacy score for each participant was computed by averaging the scores of all items. Higher total scores indicate greater perceived self-efficacy.

5.2.3.7 Behavioral Change

The behavioral change questionnaire assessed participants' self-reported changes in behavior following the intervention after four weeks. It measured the frequency of mold checks, the implementation of prevention strategies, and any noticeable changes in behavior after the learning experience. It consisted of five items with a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). For each participant, the average was calculated from all five items. Higher scores indicated a greater degree of perceived behavioral change observed by participants.

5.2.4 Data Analysis

Inferential statistical analysis was conducted to assess the effectiveness of the two learning interventions across multiple measurements. This analysis aimed to determine whether the observed differences between the groups were statistically significant.

First, the dataset was screened for completeness to remove invalid or incomplete responses. Within the post-test questionnaire, an attention check question was included: *"I will answer this questionnaire seriously, so for this question I will choose DISAGREE"*. Participants who selected any response other than "Disagree" were considered to have failed the attention check, resulting in the exclusion of their data. Consequently, 10 out of the 120 responses were eliminated (n = 4 from game learning and n = 6 participants from video learning) from the analysis.

Second, the normality of each outcome variable was assessed using the Kolmogorov-Smirnov test (Razali & Wah, 2011), supported by visual inspections such as histograms and plots. The test indicated that the responses for each measurement were not normally distributed. Therefore, Mann–Whitney U tests were used to test the significance between groups.

Third, within-group comparisons (e.g., pretest vs. posttest, and posttest vs. retention) were conducted using the Wilcoxon signed-rank test when data violated normality assumptions. This non-parametric approach was chosen to appropriately assess changes over time within each intervention group for paired samples.

Lastly, for each outcome measure, effect sizes were calculated to evaluate the magnitude of observed differences. For between-group comparisons, Cohen's d was determined by calculating the mean difference between the two groups and then dividing the result by the pooled standard deviation: Cohen's $d = (M_2 - M_1) / SD_{pooled}$, where $SD_{pooled} = \sqrt{((SD_1^2 + SD_2^2) / 2)}$ (Cohen, 2013). For within-group comparisons, Cohen's d was determined by dividing the mean of the differences by the standard deviation of the difference from paired samples: Cohen's $d = M_{\text{Difference}} / SD_{\text{Difference}}$ (Dankel & Loenneke, 2021).

5.2.5 Participants and Experiment Session

This study employed a non-probabilistic convenience sampling strategy, with a total of 120 participants (60 per group) recruited from the general public. Efforts were made to ensure diversity in age, household type, and socio-demographic background. A power analysis with a large effect size ($d = 0.8$), a significance level of $\alpha = 0.05$, a statistical power of $1 - \beta = 0.80$, and a two-tailed test to detect the mean difference between two independent groups was conducted using G*Power 3.1.9.7, indicating 26 participants as the required sample size for each group. Given that this study involved a four-week retention test, where sample sizes might drop for the retention test, a larger sample size of 60 participants for each group was selected. This sample size aligns with those reported in related studies in the field, such as Tarng et al. (2016) with n = 56, Zhang and Robb (2021) with n = 60, Paes et al. (2024) with n = 50, Feng et al. (2024) with n = 40, and Domgue K et al. (2025) with n = 60. As mentioned in Section 2.4, 10 participants failed the attention check, resulting in 56 participants valid for the game group and 54 participants for the video group. Also, the number of participants completing the retention test dropped to 36 for the game group and 33 for the video group.

Participants were recruited using flyers and word of mouth. Prior to participation, participants were informed about the study through an information sheet and were required to sign a consent form. As a token of appreciation, each participant received a NZD 10 supermarket voucher upon completion. This experiment received a Low-Risk Notification (4000030296) from the Massey University Human Ethics Committee. Figure 5.5 depicts participants taking part in the experimental session, including both the game and video-based learning groups.

Figure 5.5: Participants engaging in game (left) and video learning (right) sessions during the experiment

Participants were required to meet basic inclusion criteria: they had to be 18 years of age or older and able to read and understand English sufficiently to complete the study materials. No additional exclusion criteria were applied, and prior gaming experience was not required for participation. All participants completed the experiment using laptop computers provided by the research team.

A detailed breakdown of participant demographics, including gender, housing type, and video game frequency, is provided in Table 5.2. The demographic distribution included a higher proportion of women than men across both groups. Participants represented a variety of living situations, with the most common housing types being standalone houses, followed by townhouses and apartments or flats. In terms of video game familiarity, most participants reported playing video games occasionally, with a smaller proportion playing frequently or daily. Notably, a considerable number of participants indicated that they rarely or never engage with video games, suggesting varying levels of prior exposure to digital gaming environments.

Table 5.2: Sample demographics

Parameter	Sample (n = 110)			
	Game group (*n* = 56)		Video group (*n* = 54)	
	#	%	#	%
Gender				
Man	23	41%	23	43%
Woman	33	59%	31	57%
Type of house				
Apartment/Flat	14	25%	14	26%
Standalone house	27	48%	22	41%
Townhouse	15	27%	18	33%
Frequency of playing video games				
Never	11	20%	15	28%
A few times a year	16	28%	19	35%
A few times a month	14	25%	16	30%
A few times a week	9	16%	3	5%
Everyday	6	11%	1	2%

5.3 Results

5.3.1 Knowledge acquisition and retention

The knowledge scores obtained by participants in the game-based and video-based learning groups were analyzed at three stages: before learning experience (Pre), immediately after learning experience (Post), and four weeks after learning experience (Ret). Figure 5.6 displays these scores using box plots. The data reveal a statistically significant increase in knowledge from Pre to Post for both the game-based and video-based groups. However, when comparing Post to Ret scores, a statistically significant decline in knowledge was observed only in the video-based group. The game-based group did not show a significant decline over the same period, indicating better knowledge retention (

Table 5.3). Regarding group comparisons, no significant differences were found between the game and video-based learning groups at Pre or Post, suggesting comparable learning outcomes immediately after the intervention (Post). However, four weeks later (Ret), the game-based group outperformed the video-based group in knowledge retention, with a statistically significant difference, reflecting a medium-to-large effect size in favor of game-based learning (Table 5.4).

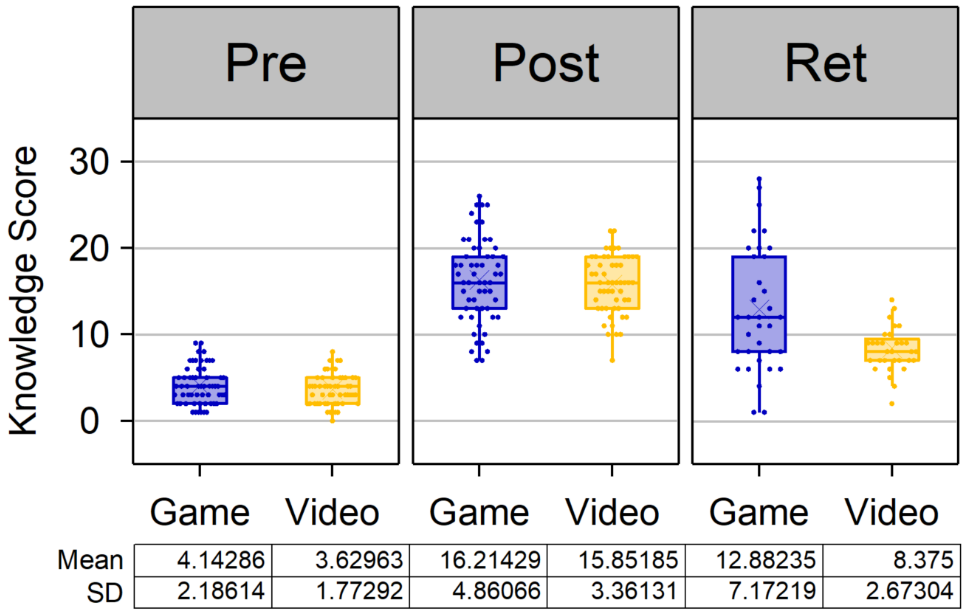


Figure 5.6: Participants' knowledge scores before the learning (Pre), after the learning (Post), and after four weeks (Ret) in the game and video learning conditions

Table 5.3: Comparison of the knowledge scores before the learning (Pre), after the learning (Post), and after four weeks (Ret) for the game and video-based learning conditions

Metric	Pre vs Post		Post vs Ret	
	Game	Video	Game	Video
Z	-6.514	-6.400	-.883	-4.868
p	<.001	<.001	.377	<.001
d	2.742	3.883	0.158	4.146

Table 5.4: Comparison between knowledge scores of the game and video-based learning conditions for the knowledge assessment done before the learning (Pre), after the learning (Post), and after four weeks (Ret)

Game vs Video	Pre	Post	Ret
U	1337.5	1462.0	341.0
Z	-1.056	-.300	-2.614
p	.291	.764	.009
d	0.257	0.086	0.832

5.3.2 Analysis of Intrinsic Motivation

This section presents the analysis of intrinsic motivation scores collected from participants in both the game-based and video-based learning groups. Intrinsic motivation was assessed immediately after the learning intervention (Post) to explore differences between the two approaches. Figure 5.7 illustrates the average scores across three subscales, Interest/Enjoyment, Perceived Competence, and Pressure/Tension, using box plots. The analysis revealed a statistically significant difference in intrinsic motivation in favor of the game-based learning group. Participants who engaged in the game-based learning reported significantly higher levels of Interest/Enjoyment, with a medium effect size. Similarly, the game-based group scored significantly higher in Perceived Competence and Pressure/Tension, indicating reduced stress or anxiety compared to the video-based group. Although the effect sizes ranged from small to medium, the findings suggest that game-based learning had a meaningful positive impact on learners' intrinsic motivation across multiple dimensions when compared to traditional video-based learning (Table 5.5).

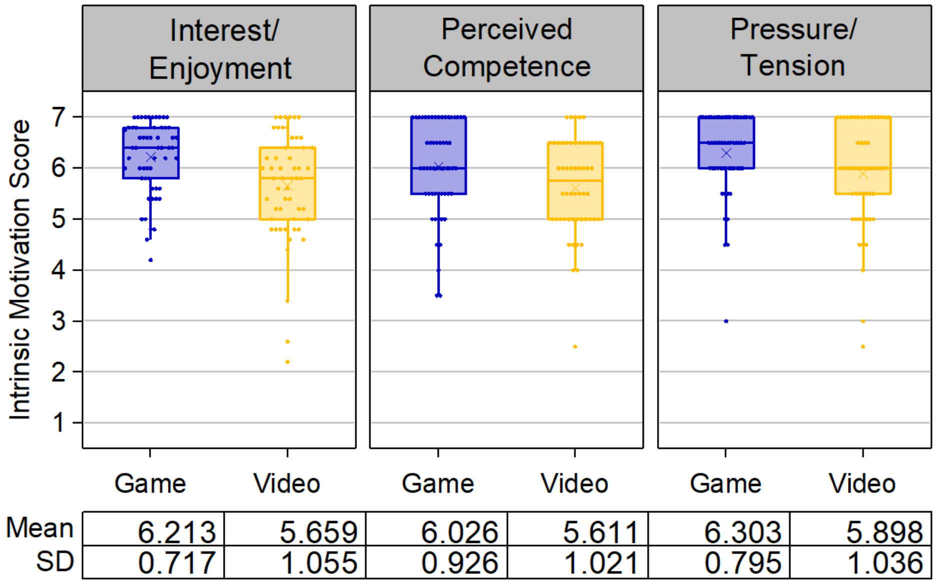


Figure 5.7: Participants' intrinsic motivation scores after the learning (Post) in the game and video-based learning conditions

Table 5.5: The results of Mann–Whitney U test for game vs video-based learning conditions for intrinsic motivation after the learning (Post)

Game vs Video	Interest/Enjoyment	Perceived Competence	Pressure/Tension
U	1024.0	1130.0	1153.0
Z	-2.929	-2.318	-2.206
p	.003	.020	.027
d	0.614	0.426	0.438

5.3.3 Analysis of Perceived System Usability (NMSUS)

This section analyzes perceived system usability scores from participants in the game-based and video-based learning groups. Usability was measured immediately after the learning session (Post) to determine whether the instructional method influenced user perceptions of system usability. The average scores are illustrated in Figure 5.8 using a box plot. The analysis revealed a statistically significant difference in perceived system usability between the two groups. Participants in the game-based learning group reported higher usability scores compared to those in the video-based group. The test confirmed that this difference was statistically significant. Cohen's d indicates a medium effect, implying that the game-based learning environment was perceived as notably more usable and user-friendly than the video-based alternative (Table 5.6).

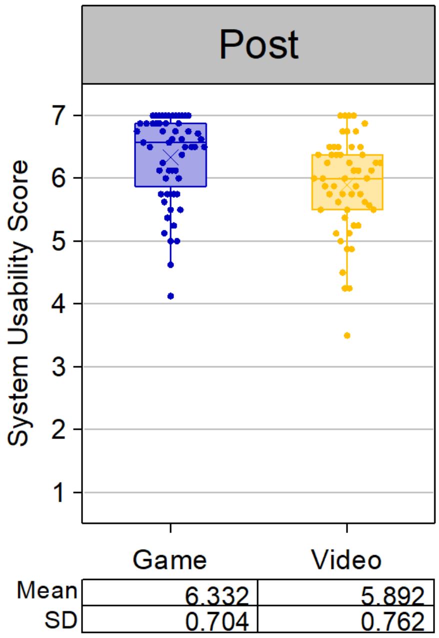


Figure 5.8: Participants' system usability scores after the learning (Post) in the game and video-based learning conditions

Table 5.6: The results of Mann–Whitney U test for game vs video-based learning conditions for system usability after the learning (Post)

Game vs Video	Value
U	950.0
Z	-3.370
p	<.001
d	0.599

5.3.4 Analysis of Task Load (TLX)

This section evaluates the task load experienced by participants in the game-based and video-based learning groups, measured immediately after the learning intervention (Post). The analysis aims to assess whether the type of instructional method influenced participants' perceived task load. The average task load scores across the six NASA-TLX subscales are presented in Figure 5.9 using box plots. The analysis revealed that participants in the game-based learning group reported significantly lower task load compared to those in the video-based group. These results indicate small to moderate effect sizes, suggesting that the game-based environment imposed less mental strain and time-related pressure on learners (Table 5.7).

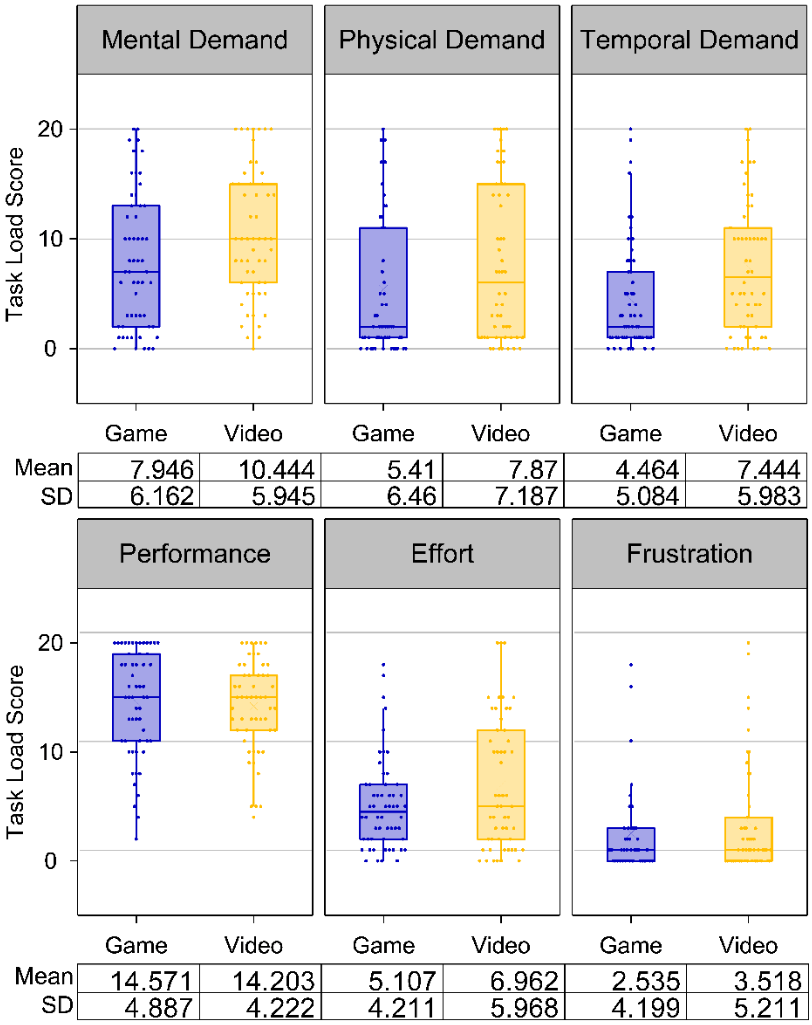


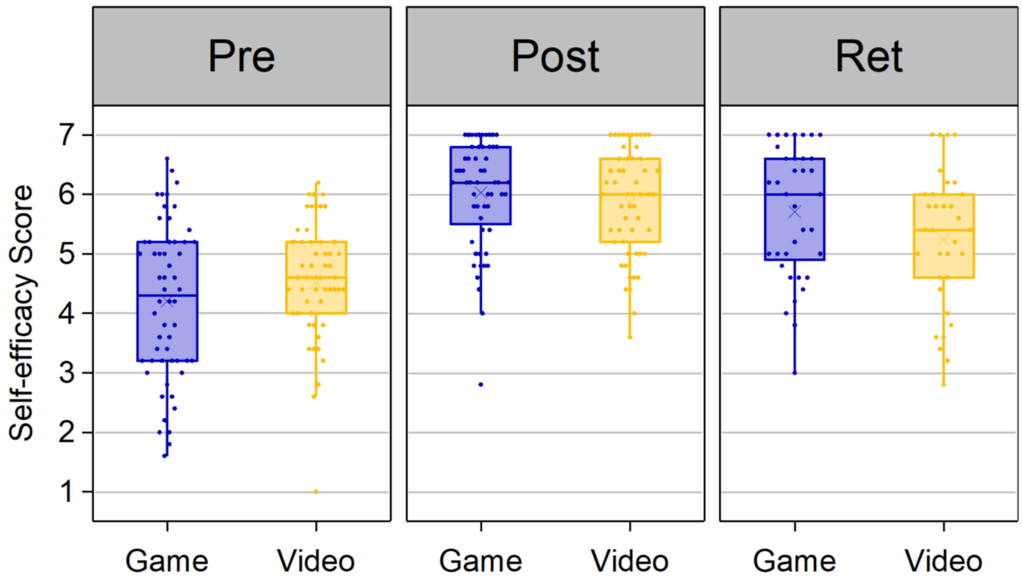
Figure 5.9: Participants' task load scores after the learning (Post) in the game and video-based learning conditions

Table 5.7: The results of Mann–Whitney U test for game vs video-based learning for task load after the learning (Post)

Game vs Video	Mental demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
U	1145.5	1188.5	1063.0	1391.5	1325.5	1387.5
Z	-2.197	-1.947	-2.7	-.724	-1.119	-.769
p	.028	.051	.007	.469	.263	.442
d	0.412	0.359	0.536	0.080	0.359	0.207

5.3.5 Analysis of Self-efficacy (GSE)

This section analyzes self-efficacy scores reported by participants in both the game-based and video-based learning groups at three stages: before learning experience (Pre), immediately after learning experience (Post), and four weeks post-learning (Ret). These scores are illustrated in Figure 5.10 using box plots. The analysis showed a statistically significant increase in self-efficacy from Pre to Post in both groups. These results indicate large effect sizes, confirming that both methods were effective in improving participants' self-efficacy immediately after the learning intervention. When comparing Post to Ret scores, a statistically significant decline in self-efficacy was observed only in the video-based group, reflecting a moderate drop in perceived self-efficacy over time (Table 5.8). In contrast, the game-based group maintained its self-efficacy scores, showing no significant decrease. The analysis also revealed no statistically significant differences between the game and video-based learning groups at either Pre or Post, indicating similar baseline and immediate outcomes. However, a trend toward significance was noted at the Ret stage, suggesting that the game-based learning group may have been more effective in sustaining self-efficacy gains over the longer term (Table 5.9).



	Pre Game	Pre Video	Post Game	Post Video	Ret Game	Ret Video
Mean	4.20714	4.51111	6.025	5.87037	5.71111	5.24242
SD	1.30508	1.09176	0.9098	0.90629	1.10835	1.15948

Figure 5.10: Participants' self-efficacy scores before the learning (Pre), after the learning (Post), and after four weeks (Ret) in the game and video learning conditions

Table 5.8: Comparison of the self-efficacy score before the learning (Pre), after the learning (Post), and after four weeks (Ret) for the game and video-based learning conditions

Metric	Pre vs Post		Post vs Ret	
	Game	Video	Game	Video
Z	-6.043	-5.562	-.861	-2.306
p	<.001	<.001	.389	.021

d	1.251	0.965	0.111	0.480

Table 5.9: Comparison between self-efficacy score of the game and video-based learning conditions for the knowledge assessment done before the learning (Pre), after the learning (Post), and after four weeks (Ret)

Game vs Video	Pre	Post	Ret
U	1297.0	1350.0	456.5
Z	-1.288	-.974	-1.658
p	.198	.330	.097
d	0.252	0.170	0.413

5.3.6 Analysis of Behavioral Change

This section examines behavioral change scores reported by participants in the game-based and video-based learning groups, measured four weeks after the learning intervention (Ret). The objective was to determine whether the type of instructional method influenced sustained behavioral change over time. The results are presented in Figure 5.11 using box plots. The analysis revealed no statistically significant difference in behavioral change between the two groups after four weeks. Although the game-based learning group reported slightly higher behavioral change scores than the video-based learning group, the difference was not statistically significant. The effect size was very small, indicating minimal practical significance. These findings suggest that both instructional methods had a similar impact on participants' ability to implement and sustain behavioral changes one month after the learning experience. Neither method demonstrated a clear advantage in promoting long-term behavioral transformation (Table 5.10).

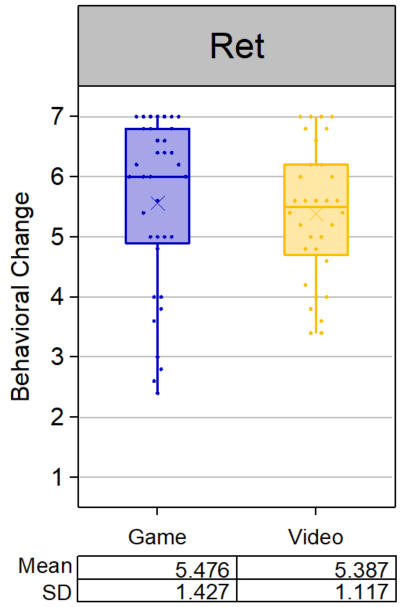


Figure 5.11: Participants' behavioral change scores after four weeks of learning (Ret) in the game and video-based learning conditions

Table 5.10: Comparison between behavioral change scores of the game and video-based learning conditions for the behavioral change assessment done after four weeks (Ret)

Game vs Video	Value
U	492.5
Z	-.663
p	.507
d	0.069

5.4 Discussion

This study aimed to develop and evaluate the effectiveness of a serious game compared to video-based learning aimed at educating the general public on mold prevention techniques in residential settings. The evaluation focused on key learning performance metrics, including knowledge, self-efficacy, intrinsic motivation, system usability, task load, and behavioral change. A controlled between-subjects experiment was conducted to assess the learning and behavioral outcomes of both learning modalities.

Both the game-based and video-based learning conditions resulted in significant improvements in knowledge immediately after the learning experience (Post), with large effect sizes for both groups. However, only the game-based learning group maintained their knowledge after four weeks (Ret), showing no significant decline, while the video-based learning group experienced a significant decrease in knowledge. Notably, the game-based learning group outperformed the video group in knowledge retention, with a statistically significant difference and a medium-to-large effect size. These findings are consistent with previous literature indicating that serious games can effectively support knowledge acquisition and improve long-term knowledge retention. For example, Sitzmann (2011) conducted a meta-analysis of 65 studies involving over 6,000 participants and found that trainees taught with simulation games demonstrated 11% higher declarative knowledge and 9% greater retention compared to those receiving traditional instruction. Similarly, Wouters, Nimwegen, et al. (2013), in a meta-analysis covering 77 studies, reported that serious games were significantly more effective than conventional instructional methods in promoting both learning and retention. They further noted that the effectiveness of serious games was enhanced when games were used in combination with other instructional strategies, involved multiple sessions, and encouraged collaborative learning. More recent empirical studies have consistently demonstrated the superiority of serious games over traditional and video-based instructional methods in enhancing knowledge acquisition and retention. For instance, L. Hu et al. (2021) developed a serious game aimed at training undergraduate medical students in neonatal resuscitation. Their randomized controlled trial revealed that students who engaged with the game exhibited significantly higher long-term knowledge retention compared to those who underwent traditional training methods. Additionally, Chen (2025) explored the impact of low-tech serious games in higher education settings. The study concluded that students who engaged in serious game-based learning retained more information than those who attended traditional lecture-based classes.

In this study, the game-based learning group reported significantly higher intrinsic motivation scores than the video-based learning group. This difference, with small to medium effect sizes, suggests that the game better satisfied participants' psychological needs for autonomy, competence, and low anxiety, critical components of sustained learning motivation according to the Self-Determination Theory. This aligns with prior research that identifies gamification elements as strong drivers of intrinsic motivation. For instance, a study by Söbke et al. (2020) compared serious gaming and traditional learning methods and found that serious gaming led to higher intrinsic motivation along with lower mental load, compared to traditional methods. Additionally, Sailer et al. (2017) conducted an experimental study examining the effects of gamification on intrinsic motivation and performance. The study found that gamified learning environments, which included elements like narrative, avatars, challenge, feedback, and rewards, significantly increased self-reported intrinsic motivation among participants.

System usability scores indicated that the serious game was perceived as significantly more user-friendly than the video-based method, with a medium effect size. This reported greater usability likely contributed to the enhanced motivation and knowledge retention observed in the game-based learning group. These findings are consistent with prior research showing that serious games can reduce cognitive load while enhancing engagement (Sitzmann, 2011). Studies have shown that well-designed games present information through interactive narratives and meaningful feedback, which helps learners process complex material more efficiently than passive methods such as video instruction (Plass et al., 2015).

The serious game-based learning also led to significantly lower perceived task load in key aspects such as mental demand and temporal demand. These findings suggest that the game presented information in a cognitively manageable way, potentially by offering guided exploration, pacing, and modular progression. Lower task load during learning may have helped participants focus better on the material and engage with it more deeply. Although the physical demand, effort, and frustration aspects of the task load variable did not differ significantly, the general trend favored the serious game method across all TLX subscales, suggesting a more balanced and smooth learning experience.

Moreover, while participants in both groups showed significant increases in self-efficacy right after the learning experience (Post), with large effect sizes, only the video-based learning group experienced a significant decline after four weeks (Ret), while the game-based learning group maintained their gains. Although between-group differences at Ret were not statistically significant, the trend suggests that the game-based intervention may have a more stable long-term effect on learners' confidence in applying mold prevention strategies.

Despite the game group reporting slightly higher behavioral change scores after four weeks (Ret), the difference between the two groups was not statistically significant. This suggests that while serious games can enhance knowledge and motivation, these gains may not directly translate into real-world behavior without additional reinforcement. Behavioral change is a complex outcome influenced by contextual, environmental, and social factors beyond knowledge and intention. The small effect size observed aligns with existing literature emphasizing the challenge of achieving behavior change through one-time interventions alone.

While this study provides promising evidence regarding the effectiveness of serious games, several limitations should be acknowledged. Studies consistently highlight that self-reported data are prone to social desirability, recall errors, reference bias, and response-shift bias. For example, physical activity research notes that self-report methods possess several limitations in terms of their reliability and validity (Prince et al., 2008). In the following, behavioral change was measured via self-reported data collected four weeks post-intervention. It is susceptible to social desirability and recall biases. No objective validation (e.g., home inspections or behavior tracking) was conducted to corroborate these self-assessments. Also. short follow-up periods (commonly under three months) limit conclusions about sustained behavior change.

This study did not incorporate gameplay-embedded learning analytics, which limits the ability to examine how participants interacted with the game and which specific behaviors or decision patterns contributed to learning outcomes. Game learning analytics can capture granular behavioral traces such as navigation paths, time spent on tasks, error correction patterns, and strategy use. These data offer objective insights that complement self-reports and support deeper analysis of cognitive and behavioral processes in serious game environments. Future work will integrate analytics dashboards and event-logging mechanisms into the game to enable more comprehensive assessments of learning mechanisms and real-world behavioral transfer. Although the findings support the effectiveness of serious games for mold-prevention education, the specific perceptual, contextual, and spatial cognitive mechanisms were not directly measured and should be examined in future research.

5.5 Conclusion

This study demonstrates the educational potential of serious games for mold-prevention education and provides outcome-level evidence supporting their effectiveness in this domain. Both serious game-based and video-based learning improved knowledge and self-efficacy immediately after training. Only the game-based intervention sustained superior knowledge retention and intrinsic motivation after four weeks, alongside lower perceived task load and higher usability. Behavioral change did not differ between groups, indicating that improved cognition and motivation alone are insufficient to drive lasting household behavior without additional reinforcement mechanisms. Beyond comparative performance, the key contribution of this work lies in proposing a domain-specific instructional rationale for mold-prevention education. Mold risk depends on micro-level household actions that physically modify the indoor environment by altering ventilation, humidity, surface temperatures, and moisture accumulation. These processes require spatial diagnosis and situated decision-making rather than declarative recall. The serious game was therefore designed to allow learners to actively test environmental modifications and observe their consequences through immediate feedback. The superior long-term retention observed in the game condition is consistent with theoretical perspectives suggesting that interactive and spatially grounded learning environments may be well suited to mold-prevention education. However, the present study did not directly measure perceptual or spatial cognitive processes, and future research should examine these mechanisms explicitly.

From a public-health and housing-policy perspective, the findings indicate that digital learning tools can support large-scale mold-awareness and tenant-education initiatives, especially in high-risk residential environments. The divergence between cognitive gains and behavioral outcomes further suggests that effective mold-prevention education should integrate learning with structured reinforcement, such as follow-up prompts, in-home audits, or environmental checklists. Educational institutions and public agencies may therefore benefit from deploying blended strategies that combine the diagnostic strengths of serious games with procedural supports to sustain behavior change. Future research should incorporate longer retention periods, objective in-game behavioral analytics, and post-intervention field measurements of household conditions to better capture real-world learning transfer. Expanding the intervention across different climatic regions and housing typologies will further strengthen its scalability and policy relevance.

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the student and the student's main supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the student's contribution as indicated below in the Statement of Originality.

Student name:	Abdollah Baghaei Daemei
Name and title of main supervisor:	Dr Zhenan Feng
In which chapter is the manuscript/published work?	Chapter 6

Describe the contribution that the student and members of the supervisory team have made to the manuscript/published work:[1]

Abdollah Baghaei Daemei: Writing – review & editing, Writing original draft, Visualization, Resources, Methodology, Investigation, Conceptualization. Zhenan Feng: Writing – review & editing, Supervision, Methodology, Conceptualization. Daniel Paes: Writing – review & editing, Supervision, Conceptualization. Diyako Rahmani: Writing – review & editing, Methodology, Data curation, Supervision, Conceptualization.

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Baghaei Daemei, A., Feng, Z., Paes, D., (2025). Explaining Knowledge and Self-Efficacy Gains through Learner and System Factors: Comparing Game-Based and Video-Based Learning Using Structural Equation Modeling, Interactive Learning Environments (258562105)

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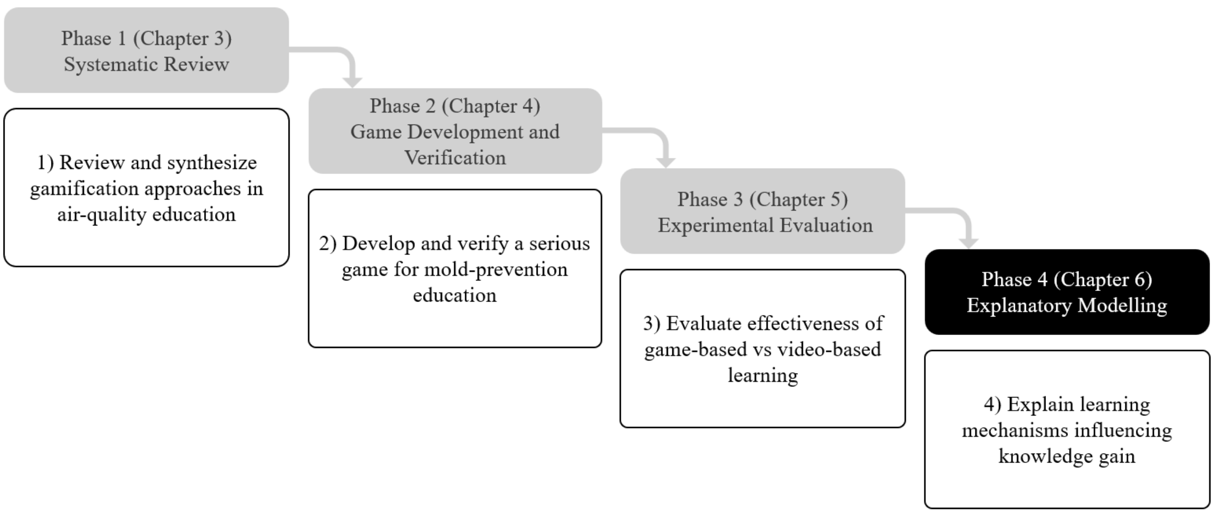
Chapter 6

Path Analysis of Learning Experience

This chapter is based on the following Journal article, which in under review:

Baghaei Daemei, A., Feng, Z., Paes, D., (2025). Explaining Knowledge and Self-Efficacy Gains through Learner and System Factors: Comparing Game-Based and Video-Based Learning Using Structural Equation Modeling, Interactive Learning Environments, Under review.

While Chapter 5 established the comparative effectiveness of the game-based and video-based interventions, the underlying mechanisms driving these outcomes remain unclear. This chapter (Chapter6) therefore extends the analysis by employing Structural Equation Modelling to examine how learner-related and system-related factors interact to influence knowledge and self-efficacy.



Chapter 6: Path Analysis of Learning Experience

6.1 Introduction

Serious games are defined as games designed for purposes beyond entertainment, often created to support learning, training, or awareness-raising (Michael & Chen, 2005). They can take various forms, ranging from analog board and card games to digital and virtual environments (Wilkinson, 2016). Over the past two decades, serious games have gained considerable attention in education, delivering a blend of engaging experiences and pedagogical structure (Checa & Bustillo, 2020; Dede, 2009). By utilizing gaming elements, such as interactivity, feedback, and goal orientation, serious games aim to enhance learners' cognitive and affective engagement, ultimately improving motivation, knowledge acquisition and retention, among other learning outcomes (Vlachopoulos & Makri, 2017).

They have been applied across diverse fields, from health education to environmental awareness, due to their versatility in adapting complex content into digestible, interactive experiences (Tan & Nurul-Asna, 2023). Despite their pedagogical potential, the underlying mechanisms through which serious games influence learning remain unclear (Sevcenko et al., 2021). Many studies focus solely on outcome measures, such as knowledge or performance improvements, without fully considering the roles of learner factors or system-related design features (Abdollah Baghaei Daemei et al., 2025; Moizer et al., 2019).

Alongside serious games, video-based learning has long been central in digital instruction. Educational videos are widely adopted due to their scalability, ease of access, and ability to present complex concepts through narration and visual demonstration (Mayer, 2009). Recent reviews highlight that videos can improve comprehension and retention when designed with multimedia principles such as signaling and segmenting (Fiorella & Mayer, 2018). However, video learning is often criticized for offering passive rather than active engagement (Kay, 2012). Compared with serious games, videos provide limited opportunities for interaction, which may constrain learners' motivation and self-efficacy (Lovreglio et al., 2021).

Despite their popularity, relatively little research has examined process-level mechanisms in game-based and video-based learning, such as how usability, cognitive load, motivation, prior knowledge and self-efficacy shape learning outcomes. This creates a gap in understanding how different instructional media, interactive versus non-interactive, affect learners through distinct cognitive and motivational pathways (Schrader, 2023).

Although numerous recent studies have explored the educational potential of serious games (Çoban & Göktaş, 2023; Feng et al., 2021; Kazar & Comu, 2021; Lovreglio et al., 2021; Mirsoleymani et al., 2022), there is a growing shift in focus toward understanding learning as a dynamic process, that is, investigating how and why learning unfolds rather than merely evaluating learning outcomes (Falloon, 2019). One effective approach for investigating learning as a process is through the use of Structural Equation Modeling (SEM) (Tarhini et al., 2017). SEM is a robust multivariate statistical technique that enables the analysis of complex relationships among observed and latent variables simultaneously (Kline, 2023). SEM is particularly suited for testing theoretical models that encompass both direct and indirect effects, allowing researchers to examine not only whether variables are related, but also how they influence each other through mediating mechanisms (Nitzl et al., 2016). In the context of educational research, SEM is increasingly utilized to uncover the interplay between cognitive, affective, and system-related factors that drive learning outcomes (Makransky & Petersen, 2019).

In the field of serious games, SEM has been employed to explore the nuanced relationships between game design elements, user experience, and learning performance. For example, Su (2015) examined software engineering students using a gamified learning system, modeling motivation, cognitive load, and academic performance with SEM. The study found that lower cognitive load reduced learning anxiety and elevated motivation, both of which significantly predicted higher academic performance. Baah et al. (2024) surveyed over 400 university students across gamified courses using SmartPLS SEM. Their findings reveal that cognitive load exerted a stronger influence than motivation on learning engagement, though both were significant predictors. The study integrates the Attention, Relevance, Confidence, and Satisfaction (ARCS) Model, SDT, and Cognitive Load Theory to illustrate how usability and task-related difficulty impact student motivation and subsequent engagement. This supports the notion that while motivation is essential, the cognitive burden can be a decisive factor in shaping learner engagement (Su, 2016). Research on serious games highlights the importance of game usability and learner experience in shaping motivation and engagement. Moreno-Ger et al. (2012) developed a usability-testing methodology tailored for serious games and demonstrated that poor interface usability diverts cognitive effort away from learning content, thereby reducing engagement and learning effectiveness. Building on these gaps, this study poses the following research questions:

- How do baseline learner factors, namely pre-test knowledge and self-efficacy, influence post-test knowledge and self-efficacy in game-based versus video-based learning?
- To what extent do system-related factors, namely usability and perceived task load, affect learners' intrinsic motivation across the two instructional media?
- Does intrinsic motivation mediate the relationship between usability, task load, and post-test outcomes (knowledge and self-efficacy), and are these pathways medium-specific?

Framed around these questions, this study aims to clarify both the cognitive and motivational mechanisms that underline learning in digital environments. This study used multi-group SEM to explore how game-based learning and video-based learning shape participants' learning outcomes. This research's design measured participants' baseline knowledge and self-efficacy before the intervention (pre-test) and then assessed their intrinsic motivation, self-efficacy, knowledge, usability and perceived task load after they completed either the game or the video-based learning (post-test). This study was particularly interested in how learners' baseline factors, such as pre-test knowledge and pre-test self-efficacy, interact with system-related factors like usability and task load to influence what they know and how confident they feel after the learning experience. The full development process of the serious game is described in detail in Abdollah Baghaei Daemei, Zhenan Feng, et al. (2025).

This approach, which incorporates both pre- and post-test measures, moves beyond simple outcome comparisons by controlling for baseline differences (e.g., pre-test knowledge and self-efficacy) and examining how affective factors (motivation) and cognitive factors (usability and task load) independently influence learning outcomes. In doing so, the study contributes to a more nuanced understanding of how digital learning environments may foster or impede learning, depending on both the learner's starting point and the design of the instructional medium. Importantly, this study positions prior knowledge as a foundational learner factor that may determine how effectively participants benefit from different media. By integrating pre-test measures of both knowledge and self-efficacy, this study moves beyond design-only explanations and examines how learners' starting points interact with usability, task load, and motivation to shape post-test outcomes.

This study extends existing SEM frameworks for digital and game-based learning by integrating both pre-test and post-test measures of learner factors. While prior research has predominantly focused on post-intervention outcomes or changes (Δ), our model integrates baseline knowledge and self-efficacy directly into the SEM framework, enabling a more precise estimation of learning gains and motivational outcomes beyond initial group differences. This approach enables a more detailed interpretation of the true effects of the intervention by isolating the influence of affective constructs (e.g., motivation) and cognitive constructs (e.g., usability, task load) while controlling for individual differences in baseline knowledge and self-efficacy. For instance, a study on digital game-based mathematics learning demonstrated the importance of modelling pre-test scores as covariates, which enables a thorough interpretation of post-test learning and motivational changes by accounting for initial group differences (All et al., 2017; Hung et al., 2014). Similarly, recent research in online learning contexts has shown that incorporating pre-intervention self-efficacy and knowledge in SEM frameworks significantly improves the validity of models explaining course satisfaction and performance (Blaak et al., 2025).

Furthermore, the model advances theoretical understanding by positioning motivation as a mediator between usability, task load, and learning outcomes. Previous studies have typically considered motivation as an outcome or isolated construct (Evans et al., 2024; Hu, 2008). In contrast, this study tests motivation's functional role in mediating the relationship between system-related factors (i.e., usability and task load) and post-intervention outcomes (i.e., self-efficacy and knowledge). This contributes to a deeper understanding of the motivational mechanisms through which learning technologies exert their effects.

6.2 Theoretical Framework

6.2.1 Prior Knowledge as a Foundation for Learning Outcomes

Prior knowledge refers to learners' existing understanding of a subject before new instruction. Classic cognitive theories posit that prior knowledge provides the mental framework onto which new information is assimilated (Cook, 2006). Indeed, prior domain knowledge has been described as *"the most important determinant of a student's learning success"*, explaining a large portion of variance in final achievement (Bandura, 1986; Brod, 2021). In practical terms, students who know more at the outset of a course tend to also know more at the end. Prior knowledge facilitates comprehension by allowing learners to make meaningful connections, reduce extraneous cognitive processing, and focus on novel material. Conversely, novices with low prior knowledge may struggle to integrate new information, although they have more room for growth (Brod, 2021). Given its centrality, prior knowledge is expected to directly enhance learning with an instructional medium (Alonso-Fernandez et al., 2019). As such, we hypothesize that:

- H1: Higher pre-test knowledge leads to higher post-test knowledge

This is consistent with extensive evidence in digital learning interventions that initial knowledge strongly predicts learning outcomes (Wang et al., 2021). Furthermore, prior knowledge may shape learners' confidence. Students entering with a strong knowledge base often feel more competent and assured in learning tasks (Wouters, van Nimwegen, et al., 2013). Empirical studies have found that prior knowledge correlates positively with self-efficacy, suggesting that familiarity with the content boosts one's belief in mastering similar content (Wang, 2023). We therefore expect that:

- H2: Higher pre-test knowledge leads to higher post-test self-efficacy

In other words, a well-prepared learner not only learns more from the instructional medium but also emerges to feel more efficacious about the subject matter (Wang et al., 2021).

6.2.2 Self-Efficacy in Learning Processes

Self-efficacy, defined by Bandura (1982) as one's belief in one's capability to succeed at specific tasks, is a crucial motivational construct in learning contexts. High self-efficacy leads learners to set challenging goals, persist through difficulties, and employ effective strategies (Williams & Rhodes, 2016). In the domain of digital learning environments, pre-intervention self-efficacy (i.e., confidence in one's ability to learn or perform well in the learning medium) can significantly influence engagement and outcomes (Lopez-Garrido, 2025). Students with higher initial self-efficacy are more likely to approach game challenges with optimism and persistence, which facilitates deeper learning. Meta-analytic evidence underscores the importance of self-efficacy: Richardson et al. (2012) found a strong correlation between self-efficacy and academic performance ($r = 0.59$). Thus, we hypothesize that:

- H3: Pre-test self-efficacy is positively related to post-test knowledge

This hypothesis aligns with social-cognitive theory, which holds that efficacious learners engage more and learn more (Williams & Rhodes, 2016). In addition, self-efficacy tends to exhibit continuity over time, especially in short interventions. Empirically, a student's confidence before an intervention is often a strong indicator of their confidence after, absent extremely disconfirming experiences (Street et al., 2022). We therefore expect that:

- H4: Pre- and post-test self-efficacy are positively related

In other words, we expect that learners with high self-belief are likely to maintain relatively higher self-belief after the learning experience. However, changes may occur: a well-designed learning environment may boost self-efficacy for those initially unsure, and failure experiences could dampen confidence for some. By modeling the path from pre- to post-self-efficacy, we account for these individual trajectories (Reyhing & Perren, 2021).

6.2.3 Design-Related Factors and Learner Motivation in Multimedia Learning

Usability and task load are critical system-related factors in multimedia learning environments that can profoundly affect the learner's experience (Dimitriadou et al., 2021). *Usability* refers to the ease of use and intuitiveness of a system's interface and mechanics, in essence, how user-friendly and accessible the system is (Nielsen, 1994). A highly usable learning environment allows learners to focus on the content and tasks without confusion or frustration caused by the interface. Prior research in educational technology emphasizes that an interface's design can either support or hinder learner motivation. As Lewis et al. (1998, p. 40) observed, *"if [an instructional multimedia interface] is poorly designed, students will not be intrinsically motivated to use the product or to learn with it. Interfaces that motivate learners are realistic, easy-to-use, challenging and engaging."* In other words, good usability is a precondition for intrinsic motivation: when controls are intuitive and feedback is clear, learners experience a sense of competence and autonomy that fuels their willingness to engage (Jeno et al., 2021). Empirical work has indeed found that improving usability can enhance learners' interest and satisfaction. For example, small-to-medium positive correlations have been documented between usability satisfaction and motivation measures such as attention and relevance (Deci & Ryan, 2013). In our study, we posit that if the learning environment is easy to navigate, with clear instructions and responsive design, learners will feel more motivated to continue and invest effort (Davis, 1989). Thus, we hypothesize that:

- H5: Usability positively influences post-test motivation

This extends technology acceptance models into the learning realm, linking perceived ease-of-use with motivational engagement (Granić & Marangunić, 2019). Notably, prior studies have rarely integrated usability and motivation in a single model – the interplay between the two "continues to remain a myth" (Hu, 2008), so our examination is expected to shed new light on this relationship.

Task load, on the other hand, refers to the cognitive demand and mental effort required to perform a given task (Chang et al., 2017). We draw on cognitive load theory (Sweller, 2011) to conceptualize task load: if the game's challenges impose excessive working memory demand (e.g., due to complex instructions, time pressure, or multitasking requirements), learners may experience cognitive overload, which can lead to frustration, fatigue, and ultimately demotivation (Yen & Lin, 2020). In contrast, an educational medium that appropriately matches difficulty to the learner's cognitive abilities, providing challenge without overload, can induce a state of flow or productive engagement (Hamari et al., 2016). There is growing evidence of an inverse relationship between cognitive load and motivation. When instructional strategies reduce extraneous cognitive load, students report higher autonomous motivation and engagement (Paas et al., 2003). A recent large-scale study by Evans et al. (2024) found that teaching methods that lightened students' cognitive load were associated with increased motivation and engagement, as well as better achievement. We therefore hypothesize that:

- H6: Task load negatively influences post-test motivation

In practical terms, if the educational environment feels overly demanding or mentally taxing, learners' interest and drive continue to diminish. By measuring *perceived* task load (e.g., via a post-test scale akin to NASA-TLX or cognitive load ratings (Hart, 2006)), our model captures the learner's subjective workload and its impact on motivation.

Motivation is a pivotal construct in learning. We define motivation as the learner's drive, interest, and willingness to engage in the learning activity, as measured after gameplay. The educational learning environment is intended to leverage motivational affordances (e.g., fantasy, feedback, challenge) to spark learners' interest and enjoyment in the subject matter. High motivation is not only an outcome of engaging learning environments (either serious games or video-based instruction) but also a facilitator of deeper learning processes.

Motivated learners tend to immerse themselves more fully, expend greater effort, persist longer, and use more effective learning strategies (Pintrich & De Groot, 1990). These behaviors, in turn, directly contribute to improved comprehension, knowledge acquisition, and retention. Empirical studies demonstrate that higher motivation is positively associated with greater academic achievement and knowledge gains across instructional settings (Eccles & Wigfield, 2020; Schunk et al., 2022). For instance, Jääskä et al. (2022) showed that serious games in higher education enhance motivation and academic success. Rodriguez-Calzada et al. (2024) demonstrated that coupling serious games with active instruction enhances learner engagement and motivation. According to Liuyufeng Li et al. (2024), gamification strategies boost intrinsic motivation by fulfilling autonomy, competence, and relatedness, central principles of the SDT. Together, this evidence suggests that motivated learners are more likely to engage deeply with the material, leading to measurable gains in knowledge as well as self-efficacy. Therefore, we posit direct effects of motivation on the key learning outcomes of knowledge and self-efficacy gains. When learners are more motivated, they are likely to engage in deeper cognitive processing of the material, leading to higher post-test knowledge. In other words:

- H7: Motivation positively influences post-test knowledge

This hypothesis is grounded in cognitive-motivational theories such as the Cognitive-Affective Theory of Learning with Media (Moreno & Mayer, 2007), which asserts that motivational factors mediate learning by increasing or decreasing cognitive engagement. Highly motivated learners invest the mental effort to organize and integrate new information, whereas unmotivated learners may coast or disengage, limiting learning even if capacity is available. While motivation alone does not guarantee learning, it creates the conditions for learning to occur. Empirical research supports this link. For example, de Boer et al. (2018) found that motivation significantly predicted academic achievement, even when controlling for intelligence (motivational effect was small to moderate). We thus expect that participants with higher motivation will demonstrate greater knowledge gains post-test. Finally, we hypothesize that:

- H8: Motivation positively influences post-test self-efficacy

The reasoning here is twofold. On one hand, motivated learners likely engage more and achieve more during the learning experience, providing them with mastery experiences that strengthen their self-efficacy (Bandura, 2014). On the other hand, there is a reciprocal relationship whereby motivation and self-efficacy reinforce each other in a learning cycle. If the learning medium succeeds in motivating the learner, that engagement can yield a sense of accomplishment and confidence by the end of the session. Prior studies have observed this connection. For instance, Makransky and Petersen (2019) found that increases in students' intrinsic motivation during a VR learning simulation were significantly related to increases in their self-efficacy. In their model, motivation boosted self-efficacy, which then contributed to learning.

Importantly, our framework highlights motivation as a mediator between the system-related factors (usability, task load) and the learning outcomes (knowledge and self-efficacy gains). Rather than expecting a highly usable, low-load game to produce learning gains on its own, we propose that these system-related factors work by first influencing the learner's motivational state, which then affects learning. This is consistent with theoretical models of user experience and learning. For example, Keller's ARCS model (Keller, 2010) emphasizes that designs that capture attention and provide satisfaction will enhance learners' motivation, leading to better learning outcomes. In our context, we anticipate that a seamless interface (high usability) and an optimally challenging task (manageable load) will create a more enjoyable and engaging experience, thus boosting the learner's motivation to learn. That motivation, in turn, will lead to greater knowledge acquisition and a stronger sense of efficacy. The mediation test is used to confirm whether the effect of good design on learning outcomes operates through increased learner motivation. This focus addresses a gap in prior research: although motivation is often cited as a benefit of digital learning environments, few studies have explicitly examined motivational mediation in the relationship between the learning environment design and learning outcomes.

6.3 Method

6.3.1 Experimental Design

A between-subjects experimental design was implemented to compare two instructional methods: game-based learning and video-based learning. Participants were randomly assigned to one of the two groups. Both interventions delivered identical educational content and learning outcomes. The procedure consisted of two phases: pre-test and post-test. The pre-test measured baseline knowledge and self-efficacy. The second phase involved exposure to either the serious game or the video. The post-test measured knowledge, self-efficacy, motivation, task load, and usability immediately after the intervention. Figure 1 illustrates the experimental design process.

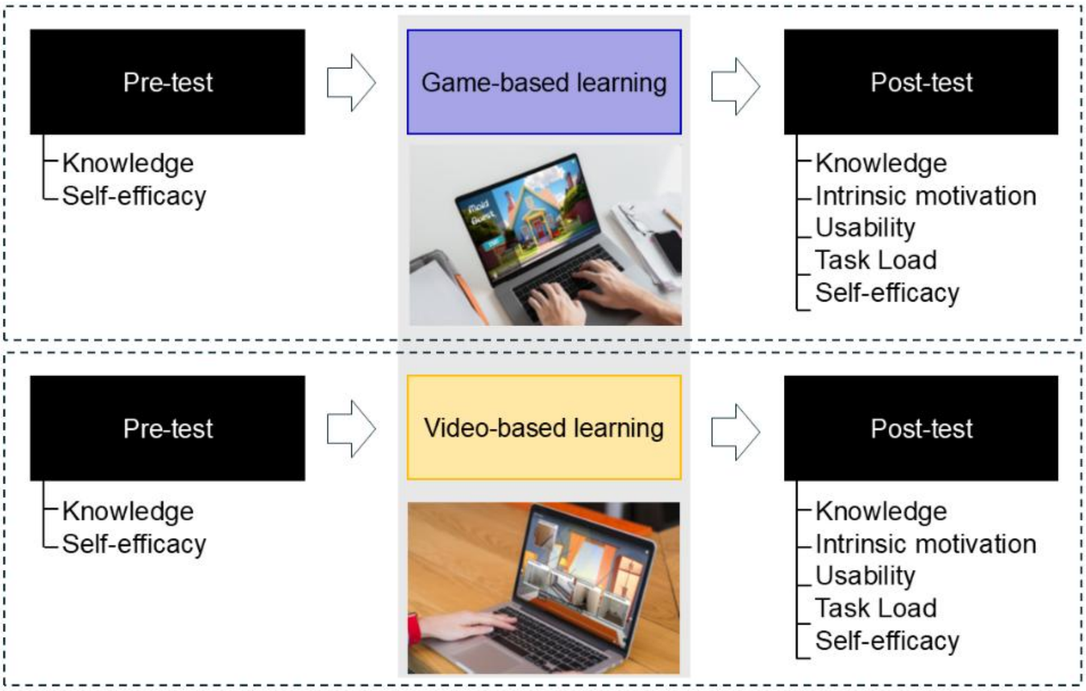


Figure 6.1: Experimental design framework

6.3.2 Participants

This study employed a non-probabilistic convenience sampling strategy, with a total of 120 participants (60 per group) recruited from the general public, using flyers and word of mouth. Efforts were made to ensure diversity in age, household type, and socio-demographic background. The dataset was screened for completeness to remove invalid or incomplete responses. Within the post-test questionnaire, an attention check question was included: "I will answer this questionnaire seriously, so for this question I will choose DISAGREE". Participants who selected any response other than "Disagree" were considered to have failed the attention check, resulting in the exclusion of their data. 10 out of the 120 responses were removed (n = 4 participants from game learning and n = 6 from video learning) from the analysis. Consequently, the dataset comprised 110 students randomly assigned to either the Game (n = 56) or Video (n = 54) condition.

Prior to participation, participants were informed about the study through an information sheet and were required to sign a consent form. As a token of appreciation, each participant received an NZD 10 supermarket voucher upon completion. This experiment received a Low-Risk Notification (4000030296) from the Massey University Human Ethics Committee. A detailed breakdown of participant demographics, including gender, housing type, and video game frequency, is provided in Table 1.

Table 6.1: Sample demographics

Parameter	Sample (n = 110)			
	Game group (*n* = 56)		Video group (*n* = 54)	
	#	%	#	%
Gender				
Man	23	41%	23	43%
Woman	33	59%	31	57%
Type of house				
Apartment/Flat	14	25%	14	26%
Standalone house	27	48%	22	41%
Townhouse	15	27%	18	33%
Frequency of playing video games				
Never	11	20%	15	28%
A few times a year	16	28%	19	35%
A few times a month	14	25%	16	30%

A few times a week	9	16%	3	5%
Everyday	6	11%	1	2%

Although statistical power in SEM depends on effect sizes, model complexity, and indicator quality rather than a pre-defined sample size, our sample of 110 (106 analyzed) is within commonly accepted bounds for path models with moderate-to-strong effects. Methodological texts (e.g., (Kline, 2016)) note that N ≈ 100–200 typically yields stable fit and parameter estimates for models of this size, and simulation work (e.g., (MacCallum et al., 1996; Wolf et al., 2013)) shows that with standardized loadings ⩾ .60 and structural paths ⩾ .30–.50, samples around 100–150 generally provide adequate power and acceptable Type I/II error rates. In our study, the principal significant paths were large (i.e., β = .77, .72, .35), we used bootstrapped CIs (2,000 resamples), and the measurement model showed good reliability/fit, all of which support adequate power for detecting the effects we report. We acknowledge that multi-group estimation reduces per-group sample (≈ 50–56), so the design is conservative for small effects; accordingly, we interpret non-significant paths cautiously and recommend replication with larger samples to detect small coefficients.

6.4 Measurements

6.4.1 Knowledge

An open-ended questionnaire was used to assess participants' knowledge to identify mold-prone areas (module 1), understand the essential conditions for mold growth (module 2), recognize temperature and humidity ranges to prevent mold growth (module 3), and apply prevention strategies (module 4). Participants' responses were manually scored. For the first module, correct answers included four spots in the kitchen, five spots in the bedroom and six spots in the bathroom. Participants obtained 1 score for each correct spot mentioned in their responses. For the second module, correct answers included four key elements: moisture, cold surface, nutrients, and spores. Participants obtained 1 score for each correct item mentioned in their responses. For the third module, correct answers included two items, including temperature (20-24°C) and humidity (40-60%). For the fourth module, the correct answers included nine mold prevention strategies. As a result, a participant could score between 0 to 30 points in total for the four modules. The same scoring method was applied for the pre-test and post-test. Inter-rater reliability was not calculated for the knowledge scoring in this study because responses were evaluated using a predetermined answer key with clearly defined scoring criteria for each module. The marking scheme specified the exact number and type of acceptable responses (e.g., predefined mold hotspots and prevention strategies), thereby minimizing subjective interpretation during scoring. Given the objective, rule-based nature of the coding process, the likelihood of scorer variability was considered low.

6.4.2 Intrinsic Motivation

In this study, a customized version of the Intrinsic Motivation Inventory (IMI) (Choi et al., 2010) was used to assess the intrinsic motivation of participants after learning. IMI is grounded in the SDT and is commonly used to evaluate how enjoyable, interesting, and engaging participants found the material, as well as their level of focus, relaxation, and enjoyment during the learning experience (Ryan & Deci, 2020). Based on the standard IMI framework developed by Deci and Ryan (2013), three subscales were selected for their relevance to this study: interest/enjoyment, perceived competence, and pressure/tension. Each subscale featured three items (9 items in total). Each item was rated using a 7-point Likert-type scale, ranging from 1 (strongly disagree) to 7 (strongly agree). For each participant, scores for each subscale were calculated by averaging the scores of the relevant items. Higher scores indicated higher levels of intrinsic motivation.

6.4.3 System Usability

The NASA Modified System Usability Scale (NMSUS) (NASA, 2023) was employed to evaluate the usability of the learning tools (game or video). This scale provides insights into how user-friendly the learning tools were and whether support was needed for efficient use. Each item was rated using a 7-point Likert-type scale, ranging from 1 (strongly disagree) to 7 (strongly agree). For each participant, their NMSUS score was averaged from eight items. Higher scores indicated higher perceived usability levels.

6.4.4 Task Load

The NASA Task Load Index (TLX) (Hart, 2006) was used to measure the perceived task load during the learning experience for both game and video groups. This scale is particularly popular in human-computer interaction, usability research, aviation, healthcare, and education contexts (Kosch et al., 2023). The NASA TLX consists of six dimensions of subjective task load, including: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Each dimension featured one item and was rated by participants on a Likert-type scale ranging from 0 to 20, where 0 indicated very low and 20 indicated very high task load.

6.4.5 Self-Efficacy

The General Self-Efficacy Scale (GSE) (Luszczynska et al., 2005) was used to evaluate participants' self-perceived capability to handle challenges related to mold prevention, ranging from general confidence to specific actions, such as identifying solutions and applying preventive strategies. In this study, the GSE was administered using a 7-point Likert-type scale, with response options ranging from 1 (completely false) to 7 (completely true). The scale consists of five items. The overall self-efficacy score for each participant was computed by averaging the scores of all items. Higher total scores indicate greater perceived self-efficacy.

6.5 Data screening and preparation

Participants were randomly assigned to either a Game condition or a Video condition. Data was collected at two stages. At pre-test, participants completed the open-ended knowledge test and the General Self-Efficacy Scale (GSE). At post-test, participants completed the same knowledge and self-efficacy questionnaires used at pre-test, along with the Intrinsic Motivation Inventory (IMI), NASA Task Load Index (TLX), and NASA Modified System Usability Scale (NMSUS). The group variable ("G") coded the condition (1 = Game, 2 = Video). The raw dataset contained 48 variables, including the group variable and all item responses. All data were inspected for univariate and multivariate normality before modelling. Skewness and kurtosis statistics were calculated for each item in IBM SPSS Statistics v.29; all values fell within the ±2.2 range, indicating approximate normality (Schmitz et al., 1983). To assess multivariate normality, Mahalanobis distances were computed (degrees of freedom = 5, $p = .001$). Four cases with distances greater than the critical chi-square value (20.52) were removed as multivariate outliers. A second Mahalanobis check showed the maximum distance had reduced to 18.72 (< 20.52), confirming the remaining 106 cases conformed to multivariate normality assumptions (Tugtekin & Koc, 2020).

6.6 Structural Model and Hypothesis Testing

After establishing a valid measurement model, the structural model based on the hypotheses H1 to H8 described in Section 2 (see Figure 2) was tested using multi-group SEM in R with the Lavaan package. Composite scores for each latent construct were computed by averaging item responses (knowledge scores were the proportion correct). Path coefficients were standardized and estimated separately for the Game and Video conditions. Non-parametric bootstrap resampling (2 000 iterations per group) generated 95 % confidence intervals for direct and indirect effects. Indirect effects of interest included Usability → Motivation → Self-efficacy, Task Load → Motivation → Self-efficacy and Motivation → Self-efficacy → Knowledge.

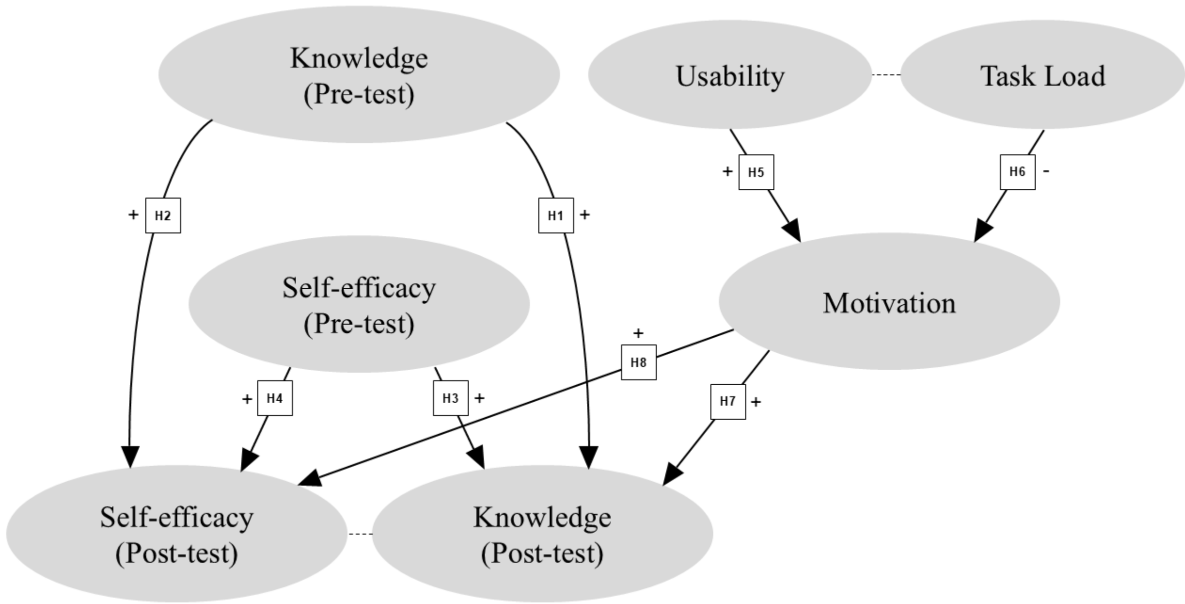


Figure 6.2: Model of hypothesized relationships

SEM was selected over alternative relational analysis techniques, such as multiple regression, simple mediation analysis, or traditional path analysis, because of the complexity and theoretical nature of the proposed model. The conceptual framework developed in this study involved multiple latent constructs, each measured by multiple observed indicators, and hypothesized both direct and indirect relationships among them. Unlike multiple regression, which examines relationships between observed composite variables independently, SEM allows the simultaneous estimation of multiple interdependent relationships within a single coherent model while accounting for measurement error (Hair et al., 2022; Kline, 2016). SEM enables concurrent testing of measurement validity (via CFA) and structural relationships, thereby ensuring that conclusions about predictive paths are grounded in validated latent constructs. This is particularly important in educational and psychological research, where measurement error can substantially bias parameter estimates. Therefore, SEM was considered methodologically appropriate for examining the theoretically integrated model of learner-related and system-related factors influencing knowledge and behavioral outcomes.

6.7 Analysis

The data analysis proceeded through several clearly defined stages. First, we assessed the normality of the dataset to confirm its appropriateness for subsequent statistical tests. Next, a Confirmatory Factor Analysis (CFA) was applied to verify the validity of the measurement models. Building on that, SEM was used to examine the hypothesized relationships among the variables. SEM is a robust statistical approach that enables simultaneous modelling of complex associations between observed indicators and latent constructs (Byrne, 2016). The measurement model was assessed using CFA in IBM SPSS AMOS v.29. This software offers an intuitive platform for conducting advanced SEM, allowing for the estimation of models that involve multiple dependent variables and mediators, capabilities that exceed those of conventional multivariate techniques (Do-Thi & Do, 2022).

The hypothesized structural paths were then estimated using multi-group SEM in R with the Lavaan package, which offers robust procedures for multi-group analysis and bootstrapping (Rosseel, 2012). Model fit was evaluated using multiple indices, including the chi-square statistic (χ^2), the Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR). The structural paths corresponding to hypotheses H1–H8 (see Section 2) were then examined. Direct, indirect, and total effects were estimated, with significance levels derived from bias-corrected bootstrap confidence intervals. Standardized path coefficients (β) are reported to facilitate interpretation.

To assess normality, we examined the skewness and kurtosis of each item using IBM SPSS Statistics v.29. None of the items exceeded the ±2.2 threshold, indicating that the data were approximately normally distributed (Schmitz et al., 1983). Independent samples *t*-tests showed significant differences between the Game and Video groups for task load ($t(108) = -2.44$, $p = .016$, $d = -0.47$), usability ($t(108) = 3.14$, $p = .002$, $d = 0.60$), and motivation ($t(108) = 3.11$, $p = .002$, $d = 0.60$). No significant group differences were found for knowledge or self-efficacy ($p > .05$).

Table 6.2: Descriptive statistics and independent samples t-tests comparing game and video groups for study variables by group

Construct	Game		Video		t(df≈)	p	Cohen's *d*
	M	SD	M	SD			
Knowledge (Pre)	0.60	0.32	0.53	0.25	1.30	.197	0.25
Knowledge (Post)	2.37	0.71	2.36	0.46	0.11	.911	0.02
Self-Efficacy (Pre)	4.21	1.31	4.51	1.09	–1.33	.187	–0.25
Self-Efficacy (Post)	6.03	0.91	5.87	0.91	0.89	.374	0.17
Task Load (Post)	6.67	3.60	8.41	3.86	–2.44	.016	–0.47
Usability (Post)	6.33	0.70	5.89	0.76	3.14	.002	0.60
Motivation (Post)	6.19	0.68	5.70	0.95	3.11	.002	0.60

6.7.1 Measurement validation

The measurement model comprised seven latent constructs: Knowledge_pre, Knowledge_post, Self-efficacy_pre, Self-efficacy_post, Motivation_post, Task Load_post and System Usability_post. Multiple observed indicators represented each latent factor. CFA was conducted using IBM AMOS Graphics v.29 with maximum likelihood estimation (Byrne, 2016). Model fit was evaluated with the chi-square statistic (χ^2), Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA) with 90 % confidence interval (CI), Standardized Root Mean Square Residual (SRMR) and the probability of close fit (PClose). Following Hu and Bentler (1999), values of CFI > 0.90, TLI > 0.90, RMSEA < 0.08 and SRMR < 0.08 were interpreted as indicating acceptable fit.

The measurement model demonstrated an acceptable fit to the data, $\chi^2(390) = 881.12$, $p < .001$, CFI = 0.932, TLI = 0.916, RMSEA = 0.063 (90% CI = [0.056–0.070]), SRMR = 0.065, and PClose = .002, indicating that the hypothesized model adequately represented the data. All factor loadings were statistically significant ($p < .001$) and exceeded the recommended threshold of 0.50, confirming that each observed item strongly represented its corresponding latent construct.

Convergent and discriminant validity were further examined using Average Variance Extracted (AVE), Composite Reliability (CR), and Maximum Shared Variance (MSV). AVE values ranged from 0.512 (Usability) to 0.621 (Knowledge), exceeding the recommended 0.50 threshold. For every construct the MSV was lower than its AVE, and the square root of AVE exceeded all inter-construct correlations, confirming discriminant validity. Reliability was strong, with Cronbach's α values between 0.796 (Usability) and 0.851 (Knowledge) (Hair, 2009).

Table 6.3: Fit indices for the competing measurement models

Model	χ^2(df)	CFI	TLI	RMSEA [90% CI]	SRMR	PClose	Description
CFA	881.12(390)	0.932	0.916	0.063 [0.056–0.070]	0.065	.002	Measurement model
SEM	912.47(402)	0.931	0.914	0.061 [0.055–0.068]	0.066	.004	Structural model

Reliability and validity indices are presented in Table 4. All constructs demonstrate high internal consistency (Cronbach's α ≥0.80) and composite reliability (CR ≥0.80). AVE values are above 0.50, MSV values are lower than AVE for each construct, and the square roots of AVE exceed inter-construct correlations. HTMT ratios are all below 0.85, supporting convergent and discriminant validity. Usability exhibits the lowest reliability ($\alpha = 0.796$) but still meets acceptable standards.

Table 6.4: Fit indices for the confirmatory factor analysis and SEM

Construct	Cronbach's α	CR	AVE	MSV
Knowledge_pre	0.832	0.84	0.583	0.31
Knowledge_post	0.851	0.85	0.621	0.36
Self-efficacy_pre	0.808	0.81	0.512	0.28
Self-efficacy_post	0.823	0.82	0.527	0.33
Motivation	0.830	0.83	0.556	0.35
Task Load	0.802	0.81	0.521	0.30
Usability	0.796	0.80	0.512	0.29

6.7.2 Structural model results

To compare the structural models across the two groups—one exposed to games and the other to videos—a multi-group structural equation modeling was employed. The multi-group SEM model demonstrated acceptable fit to the data, $\chi^2(402) = 912.47$, $p < .001$, CFI = 0.931, TLI = 0.914, RMSEA = 0.061 (90% CI = [0.055–0.068]), SRMR = 0.066, and PClose = .004 (Table 3), indicating that the hypothesized structural model adequately represented the relationships among the constructs across both groups. Standardized path coefficients and 95 % confidence intervals are reported in Table 5. In the Game condition, only H1 (Knowledge_pre → Knowledge_post) reached significance: $\beta = 0.35$, 95 % CI = [0.10, 0.57]. All other paths were non-significant, indicating that in the Game condition, post-test knowledge was significantly predicted by baseline knowledge. In the Video condition, usability strongly predicted motivation (H5, $\beta = 0.77$, 95 % CI = [0.62, 0.89]), which in turn strongly predicted post-test self-efficacy (H8, $\beta = 0.72$, 95 % CI = [0.60, 0.83]). All other paths were non-significant. These results indicate different mechanisms of action across conditions.

Table 6.5: Standardized path coefficients and 95 % confidence intervals

Hypothesis	Game Condition	Video Condition
H1: Pre-test knowledge → Post-test knowledge	β = 0.35 [0.10, 0.57], p = .012	β = –0.01 [–0.26, 0.24], p = .938
H2: Pre-test knowledge → Post-test self-efficacy	β = 0.21 [–0.01, 0.41], p = .062	β = –0.04 [–0.27, 0.19], p = .713
H3: Pre-test self-efficacy → Post-test knowledge	β = 0.03 [–0.23, 0.25], p = .812	β = –0.17 [–0.42, 0.08], p = .183
H4: Pre- → Post-test self-efficacy	β = 0.12 [–0.14, 0.37], p = .375	β = 0.02 [–0.23, 0.28], p = .861
H5: Usability → Post-test motivation	β = 0.09 [–0.24, 0.40], p = .656	β = 0.77 [0.62, 0.89], p < .001
H6: Task load → Post-test motivation	β = 0.14 [–0.17, 0.45], p = .349	β = –0.01 [–0.28, 0.24], p = .936
H7: Motivation → Post-test knowledge	β = 0.06 [–0.28, 0.37], p = .724	β = 0.02 [–0.23, 0.24], p = .865
H8: Motivation → Post-test self-efficacy	β = 0.03 [–0.29, 0.34], p = .857	β = 0.72 [0.60, 0.83], p < .001

Indirect effects were significant only for the Video group. Usability affected self-efficacy via motivation (Usability → Motivation → Self-efficacy: β = 0.56, 95 % CI = [0.43, 0.67]) and motivation influenced knowledge through self-efficacy (Motivation → Self-efficacy → Knowledge: β = 0.10, 95 % CI = [0.01, 0.20]). No significant indirect effects were found in the Game group. To better visualize these medium-specific mechanisms, Figure 3 illustrates the tested SEM model with significant and non-significant pathways for the Game and Video conditions.

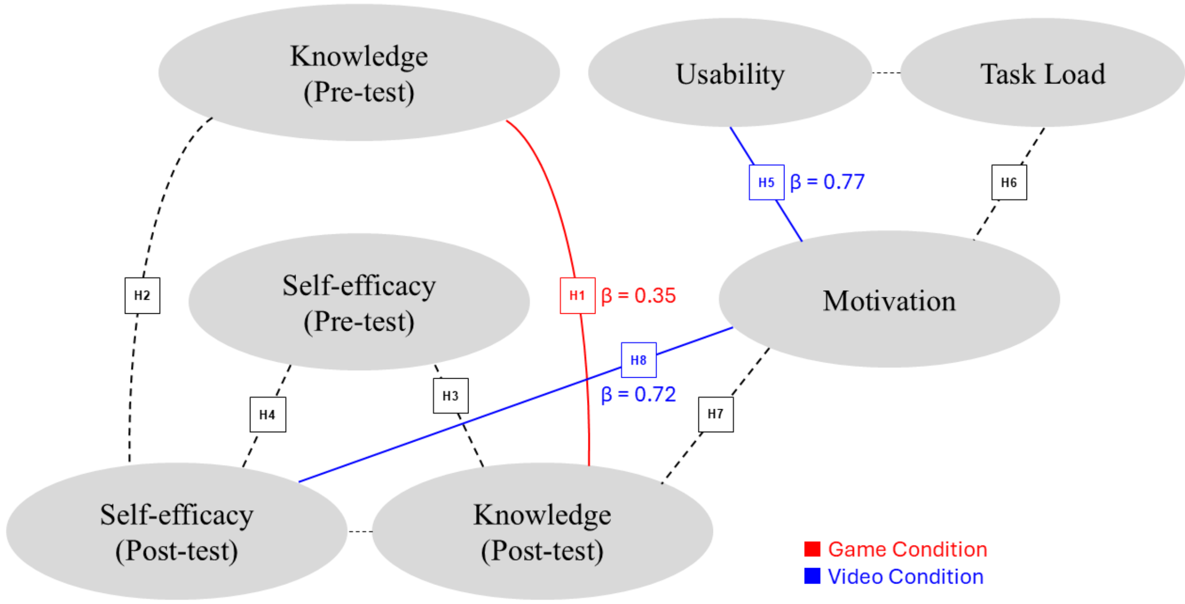


Figure 6.3: Structural equation model results for Game and Video conditions. Significant standardized paths are highlighted in red (Game) and blue (Video). The dashed lines represent non-significant hypothesized paths

6.8 Discussion

This multi-group SEM provides clear evidence that the mechanisms linking system-related factors and learner factors to outcomes are medium-specific. In the game-based condition, pre-test knowledge was the sole significant predictor of post-test knowledge, while usability, task load, and motivation did not exert detectable effects. In the video-based condition, usability predicted motivation, which in turn predicted post-test self-efficacy. Although motivation did not directly predict knowledge, there was a small indirect pathway through self-efficacy. Collectively, these patterns suggest that interactive media leverage existing knowledge, whereas video depends on interface-driven motivational arousal to strengthen learners' confidence.

The prominence of pre-test knowledge in the game condition aligns with cognitive theories positing that pre-existing schemas facilitate assimilation and integration of new information (Nemeth & Lipowsky, 2024). The interactivity of serious games likely amplifies benefits for learners who can map in-game cues onto well-organized knowledge structures, thereby allocating more resources to germane processing. This clarifies mixed results in the literature: while meta-analyses show that serious games often outperform conventional instruction on knowledge and motivation (Girard et al., 2013; Wouters, Nimwegen, et al., 2013), our model specifies for whom these advantages materialize most readily: participants with stronger knowledge foundations. Methodologically, the finding reinforces guidance to model or control pre-test knowledge levels to avoid attributing pre-existing advantages to the intervention (All et al., 2016). Practically, it points to the need for adaptive scaffolding (e.g., advance organizers, micro-tutorials, worked examples, dynamic hints) to help novices cross the threshold at which gameplay feedback translates into learning rather than mere exploration.

In the video condition, usability was a powerful predictor of motivation, aligning with the Technology Acceptance Model (Davis, 1989) and SDT, which explains how usable interfaces satisfy competence and autonomy needs, thereby fostering intrinsic motivation (Jeno et al., 2021; Ryan & Deci, 2020). Motivation, in turn, strongly predicted post-test self-efficacy, corroborating findings from immersive simulations where heightened engagement fosters mastery experiences and confidence (Makransky & Petersen, 2019). The absence of a direct link between motivation and knowledge suggests that for non-interactive media, motivation first manifests as confidence gains, with knowledge change emerging more slowly, eventually. This interpretation is consistent with the Cognitive-Affective Theory of Learning with Media, which posits that system-related factors shape affective states that subsequently influence cognition (Moreno & Mayer, 2007). Over multiple sessions, especially when paired with retrieval practice, increased self-efficacy may eventually consolidate into stable knowledge gains.

Although several studies report that cognitive load reduces engagement and performance in gamified settings (Baah et al., 2024; Su, 2015), our data showed no significant link between task load and motivation in either group. Two explanations are plausible. First, the instructional materials may have induced a moderate and relatively homogeneous workload, limiting variance and attenuating observable effects. Second, the NASA-TLX, as a global post-test-only measure, may capture overall workload effort but does not differentiate between extraneous and intrinsic cognitive load components more directly relevant for motivation (Sweller, 2011).

Motivational mediation was strong in the video condition but absent in the game. One interpretation is that well-designed games embed feedback, challenge, and goals that route learning for prepared learners through cognitive channels, leaving less variance for motivation to explain in a single session. In contrast, non-interactive video requires usability-driven engagement to sustain attention and self-evaluation, thereby elevating self-efficacy even when knowledge gains are not yet detectable (Hamari et al., 2016; Liuyufeng Li et al., 2024). This refinement complements models that have treated motivation primarily as an outcome rather than as a functional mediator (Evans et al., 2024; Hu, 2008).

For game-based learning, instructional strategies should focus on pre-test-informed adaptivity to tailor content according to learners' existing knowledge levels. Dynamic difficulty adjustment can ensure gameplay remains optimally challenging while accommodating individual differences in prior knowledge. Just-in-time scaffolds, including contextual hints, worked examples, and guided feedback, can help novices bridge knowledge gaps and make effective use of the interactive environment. Employing advance organizers to activate learners' schemas before gameplay and incorporating post-play retrieval practice can further consolidate knowledge, ensuring that gameplay translates into meaningful gains.

For video-based learning, emphasis should be placed on interface clarity to facilitate smooth navigation and reduce extraneous load. Features like pacing controls, captions, and intuitive navigation tools enhance usability and foster engagement. Incorporating signaling and segmenting principles, including visual cues and chunked content, can improve processing efficiency. Adding micro-interactions such as embedded quizzes and prompts encourages active engagement even within non-interactive formats. Pairing videos with spaced re-exposure strategies can ensure that gains in self-efficacy translate into knowledge acquisition and long-term retention.

This study contributes to theory by: (i) demonstrating medium-specific cognitive and motivational pathways; (ii) integrating pre-intervention measures into SEM, thereby improving causal interpretation and reducing bias from baseline differences (All et al., 2016); and (iii) showing that task load is not invariably predictive once usability and prior knowledge are modeled concurrently. These insights help reconcile divergent findings across the serious game literature and extend process-oriented accounts of digital learning.

We acknowledge the modest sample, single-session exposure, and reliance on composite scores as limitations of our study. Although the measurement model exhibited acceptable fit and cross-group invariance, longitudinal designs with session-level mediation, componential load measurement, and behavioral telemetry (e.g., clickstreams, dwell time) would clarify how motivational and cognitive pathways unfold over time. Comparing interactive, semi-interactive, and passive formats within a common design could further specify boundary conditions under which usability, task load, prior knowledge, and self-efficacy exert their strongest effects.

Although the theoretical framework was based on latent constructs, the structural model was estimated using composite scores derived by averaging item responses. Prior to aggregation, CFA confirmed acceptable factor loadings, reliability, and convergent validity, supporting the defensibility of this approach. The use of composites reduced model complexity and improved estimation stability given the moderate sample size. However, it is acknowledged that this approach does not fully account for measurement error and is methodologically closer to path analysis with observed variables than to a fully latent SEM. Future research with larger samples should estimate a fully latent structural model to enhance parameter precision and methodological rigor.

6.9 Conclusion

This study examined how prior knowledge, self-efficacy, usability, task load, and intrinsic motivation interact to shape learning outcomes across game-based and video-based instructional formats using a multi-group SEM approach. Our findings indicate distinct pathways: in game-based environments, learners' prior knowledge was the strongest determinant of knowledge gains, whereas in video-based formats, usability-driven motivation significantly enhanced self-efficacy but had a limited direct effect on knowledge acquisition. Importantly, task load did not significantly predict motivation or learning outcomes in either medium, suggesting that well-designed interfaces may mitigate cognitive load. These findings advance theory by clarifying that motivational mediation is conditional, not universal. While video-based learning relies heavily on usability-driven engagement to bolster learner confidence, game-based formats appear to leverage cognitive schemas more directly, benefiting learners with higher baseline knowledge. This insight refines existing frameworks by showing that instructional features interact with learner characteristics to produce different cognitive and affective outcomes. Practically, these results highlight the need for modality-specific design strategies. Game-based learning should integrate adaptive scaffolds to support novices and maximize gameplay's cognitive benefits, while video-based instruction should prioritize usability enhancements and retrieval-based reinforcement to convert motivational gains into durable knowledge improvements. Future research should adopt longitudinal and multi-session designs to track the stability of these pathways over time and investigate how interactive, semi-interactive, and passive formats can be optimally combined. By uncovering medium-specific mechanisms, this study contributes both theoretical nuance and practical guidance for developing more effective digital learning environments.

Chapter 7

Conclusion and Future Research

This final chapter brings the journey of this research to a close. It draws together the insights gained from the systematic review (Chapter 3), the design and development of the serious game (Chapter 4), the experimental comparison (Chapter 5), and the structural modelling of learning mechanisms (Chapter 6). Returning to the original research aim and objectives, this chapter reflects on what has been achieved, what has been learned, and what remains uncertain. It highlights the key theoretical and practical contributions of the study, acknowledges its limitations with transparency, and outlines meaningful directions for future research.

Chapter 7: Conclusion

7.1 Fulfilment of Research Aim and Objectives

This thesis aimed to develop and evaluate a serious game to educate the general public in New Zealand about the sources, causes, and mitigation strategies of mold in homes. To fulfil this aim, four key research objectives were formulated:

> **Objective 1:** To explore the existing studies on the application gamification in air quality education using a systematic literature review approach.
>
> **Objective 2:** To develop and prototype a serious game that educates users about mold prevention through interactive storytelling approach.
>
> **Objective 3:** To evaluate the effectiveness of the serious game against video-based learning in improving knowledge acquisition, knowledge retention, motivation, self-efficacy, behavior change, task load, and usability.
>
> **Objective 4:** To understand how learner factors and system-related factors predict learning outcomes and self-efficacy.

The following sections present a summary of how each research objective was successfully addressed throughout the course of this thesis.

7.1.1 Objective 1

The results of the objective 1 are presented in Chapter 3. This study systematically reviews the application of gamification and serious games for air quality education, addressing a critical research gap in how the games are used to promote awareness of indoor and outdoor air quality (IAQ and OAP). Poor air quality remains one of the world's major health and environmental challenges, contributing to millions of premature deaths annually and widespread respiratory illnesses such as asthma. While gamification has been applied successfully in other domains, its use in air quality education has not previously been comprehensively analyzed. Following PRISMA guidelines, the authors identified 19 eligible studies published between 2009 and 2023 from databases including Scopus, Web of Science, and IEEE Xplore. The review employed the Octalysis Framework to classify motivational "core drives" and game elements, marking the first application of Octalysis in this domain. The selected studies were analyzed according to eight research questions addressing game context, learning objectives, participant profiles, delivery platforms, educational impacts, and applied psychological theories.

Results show that most gamified applications focused on indoor environments, particularly residential buildings and asthma management, while others addressed outdoor pollution awareness. The majority targeted children and adolescents, reflecting their vulnerability to air pollutants and receptiveness to game-based learning. Commonly used platforms included smartphones, tablets, and laptops, occasionally enhanced with AR or real-time environmental sensors. Sixteen distinct game elements were identified, with "points, quest lists, instant feedback, progress bars, and avatars" being the most frequently applied. The most dominant motivational drivers were development and accomplishment and empowerment through creativity and feedback, indicating that intrinsic motivation plays a central role in sustaining engagement. Overall, the reviewed studies reported positive outcomes in user engagement, awareness, and satisfaction, alongside significant improvements in environmental knowledge.

However, challenges were noted, including limited interactivity, technical issues, and small sample sizes. Few studies employed established psychological or learning theories, such as Dewey's experiential learning, the Theory of Planned Behavior, or Elaboration Likelihood Model, underscoring the need for stronger theoretical grounding in future designs. The study introduces the first taxonomy for gamification in air quality education, categorizing seven dimensions: platform, subject matter, learning goals, target audience, interaction mode, interface type, and motivational drive. This taxonomy provides a structured reference for developing and evaluating future educational games. The review concludes that gamification can effectively increase environmental literacy, motivation, and behavioral intention, particularly among youth audiences. It highlights opportunities for advancing immersive technologies (AR/VR), AI- and IoT-integrated learning, and larger-scale implementations through policy initiatives. By bridging environmental science and behavioral education, the study establishes a foundation for interactive, scalable, and theory-informed tools that foster healthier indoor environments and more sustainable urban living.

7.1.2 Objective 2

The results of the objective 2 are presented in Chapter 4. This study presents the design, development, and preliminary evaluation of a serious game aimed at educating the public on mold prevention in residential buildings. Mold, a prevalent indoor air contaminant in New Zealand homes, poses significant health risks due to poor ventilation, high humidity, and inadequate insulation. Recognizing the need for effective public education, this research integrates serious games and environmental health communication to raise awareness and promote behavioral change. The research followed a mixed-methods design, combining prototype development, expert validation, and field evaluation. Learning objectives were structured according to Bloom's Taxonomy, focusing on remembering, understanding, and applying knowledge related to mold hotspots, growth conditions, environmental parameters, and prevention strategies. Educational content was drawn from verified public sources, national housing standards, and on-site home investigations. Twelve experts in IAQ participated in semi-structured interviews to validate the content, while six Auckland homes were visited to document real mold occurrences.

The game was developed using Articulate Storyline 360, employing Octalysis-based mechanics such as points, progress bars, narrative, avatars, mentorship, instant feedback, and milestone unlocking. The design promotes sequential learning through four interactive levels, supported by a feedback gallery and a virtual assistant ("Mr. Grumpy Moldwell"). The prototype is accessible on PCs and mobile devices, combining 2D graphics, AI-generated audio narration, and user-friendly interfaces to ensure inclusivity. A single-arm experimental study with 60 participants assessed knowledge acquisition before and after gameplay. The Wilcoxon signed-rank test showed a statistically significant improvement in post-test scores compared with pre-test scores, indicating a strong educational effect. Expert feedback further refined the optimal indoor conditions to 20–24 °C and 40–60 % RH, and highlighted nine key practical strategies (e.g., opening windows daily, venting dryers outside, using fans, and improving insulation).

This research fills a critical gap in environmental health education by being the first to develop a serious game specifically targeting mold prevention. It demonstrates how gamified learning can effectively translate scientific knowledge into actionable home practices. The study concludes that serious games are powerful, scalable tools for promoting healthy housing, energy efficiency, and public health awareness. Future work should evaluate long-term behavioral outcomes, usability, and cross-cultural adaptability using controlled experiments and extended game mechanics such as AR/VR and IoT integration.

7.1.3 Objective 3

The results of the objective 3 are presented in Chapter 5. This study investigated the effectiveness of a serious game versus traditional video-based learning for educating the public on mold prevention in residential buildings. Indoor mold poses major health and durability risks, particularly in damp and poorly ventilated homes such as those common in New Zealand. While conventional educational media (e.g., brochures, videos) can raise awareness, they often fail to sustain motivation and long-term behavioral change. This research therefore explores gamification as a novel pedagogical tool for environmental health education.

A between-subjects experimental design was adopted with 120 adult participants randomly assigned to either the serious game or video-based learning condition. The serious game was developed using Articulate Storyline 360 and structured around Bloom’s Taxonomy (remember–understand–apply) and Octalysis gamification principles (points, feedback, milestones, and mentorship). Both interventions contained identical educational content about mold hotspots, growth conditions, optimal indoor temperature/humidity, and prevention strategies. Data were collected at three points—pre-test, post-test, and four-week retention—and measured knowledge, intrinsic motivation, self-efficacy, system usability, task load, and behavioral change.

Statistical analyses using Wilcoxon and Mann–Whitney U tests revealed that both interventions significantly improved knowledge immediately after learning; however, only the game group retained knowledge after four weeks, showing a medium-to-large effect size. The game group also demonstrated higher intrinsic motivation and greater perceived system usability, as well as lower cognitive task load, indicating enhanced engagement and smoother learning. Both groups achieved comparable self-efficacy gains post-test, but the video group’s self-efficacy declined over time while the game group maintained theirs. Despite slightly higher behavioral-change scores in the game condition, no significant between-group difference emerged at the four-week follow-up, underscoring that knowledge and motivation alone may not translate into sustained behavioral change without reinforcement.

Overall, the study concludes that serious games are effective for enhancing knowledge retention, engagement, and user experience in mold prevention education, whereas video learning may yield faster short-term behavioral responses. The findings highlight the value of integrating gamified, interactive methods into public health and housing-education programs. Future work should extend retention periods, include objective behavioral measures (e.g., home audits), and test diverse demographic settings to improve external validity.

7.1.4 Objective 4

The results of the objective 4 are presented in Chapter 6. This study examined how learner-related (knowledge and self-efficacy) and system-related factors (usability, task load, and intrinsic motivation) predict learning outcomes in two digital learning media: serious games and video-based instruction. Grounded in the SDT and Cognitive Load Theory, the research explores whether the mechanisms underlying learning effectiveness differ between interactive and passive formats. A total of 110 undergraduate students were randomly assigned to either a game (n = 56) or video (n = 54) condition. Both interventions delivered identical educational content on mold prevention but differed in their interactivity and user engagement features. Participants completed pre- and post-tests measuring knowledge and general self-efficacy, as well as post-tests assessing intrinsic motivation (IMI), task load (NASA-TLX), and usability (NMSUS). Data was analyzed using multi-group Structural Equation Modeling (SEM) with 2,000 bootstrapped samples in AMOS to test eight hypothesized pathways.

Results reveal that learning mechanisms were media specific. In the game condition, pre-test knowledge strongly predicted post-test knowledge ($\beta = 0.48$, $p < .001$), suggesting that interactive learning primarily benefits learners with higher prior knowledge. Neither usability nor motivation significantly predicted post-test outcomes. In contrast, in the video condition, a strong usability → motivation → self-efficacy pathway emerged ($\beta = 0.77$ and $\beta = 0.72$, respectively), indicating that well-designed interfaces can enhance motivation and confidence in passive learning. Task load did not significantly affect learning outcomes in either group. These findings underscore that games and videos engage distinct cognitive and motivational routes. Serious games support schema activation and cognitive integration, while video-based learning depends on usability-driven motivational arousal to sustain engagement and self-efficacy. The study provides empirical evidence that medium characteristics moderate the predictive relationships among cognitive, motivational, and performance constructs.

The research concludes that serious games are effective tools for deep knowledge construction, whereas videos may serve better for confidence-building when usability and interface quality are high. The study contributes to the literature on digital pedagogy by clarifying the differential predictive pathways in multimedia learning environments and offers insights for designing tailored educational technologies that balance usability, cognitive demand, and intrinsic motivation.

7.2 Research Contributions

7.2.1 Significance of the Study

To date, a comprehensive exploration of the educational applications of gamification in the context of air quality is lacking in the existing literature. The significance of this study lies in its exploration of gamification as an innovative and alternative approach to addressing the paramount issue of indoor mold in residential buildings. With indoor air pollution posing severe threats to human health, causing respiratory problems (i.e., asthma management) and cardiovascular diseases, and contributing to environmental degradation, the need for effective educational tools becomes crucial.

Through our systematic literature review, it has come to our attention that there is a notable gap in existing studies. Specifically, no studies that have focused on mold prevention strategies, so this is the first attempt to develop and measure the effectiveness of a serious game in the subject matter to assess users' knowledge and behavioral change compared with traditional training. This gap in the literature presents an opportunity for this study to contribute novel insights into the educational potential and impact of serious games in knowledge acquisition and behavioral change, filling a void in current research.

Although a growing body of research has investigated the application of serious games in various topics, there remains a critical gap in the literature regarding their use for mold prevention in residential buildings. Mold growth is a significant public health issue, especially in regions with high humidity or inadequate ventilation, like New Zealand, and it is closely linked to poor indoor environmental quality and occupant behavior. Despite the clear relevance of this topic to health and sustainability goals, no existing studies have focused on designing, implementing, or evaluating serious games as a means of educating the general public about mold risks and prevention strategies. This research addresses that gap by developing and assessing a serious game aimed at enhancing awareness, knowledge, and behavior related to mold prevention. The research presented is also aligned with the following Sustainable Development Goals (SDGs):

> *Good Health and Well-being (#3) Target 3.9:* By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination. The study recognizes the severe threats posed by air pollution to human health, specifically addressing respiratory problems like asthma and cardiovascular diseases. The goal is to contribute to reducing the adverse health impacts associated with air quality issues, aligning with the objective of Target 3.9.
>
> *Sustainable Cities and Communities (#11) Target 11.6:* By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management. The study highlights the significance of investigating the educational potential of architectural elements, such as windows, in influencing indoor environments. This aligns with the broader goal of creating sustainable and resilient cities, specifically addressing the adverse environmental impact, including a focus on air quality. Target 11.6 emphasizes the importance of considering air quality in urban settings, which resonates with the study's exploration of architectural features in the context of air quality education.

7.2.2 Theoretical Contributions

This research makes theoretical contributions to the interdisciplinary fields of gamification and the built environment. It advances theoretical understanding by developing and empirically validating a conceptual framework that integrates learner-related factors (such as prior knowledge and self-efficacy) with system-related factors (including usability, task load, and intrinsic motivation) to explain knowledge gain in digital learning environments. The model articulates the mechanisms through which game environments enhance knowledge gain and retention, motivation, and confidence in learning. This integration represents a novel contribution to educational technology literature, as few prior studies have simultaneously examined these constructs within an environmental health context and no studies have examined the impact of serious games to educated public on mold prevention.

A further theoretical advancement lies in the application and extension of the Octalysis Framework within the environmental education domain. The study demonstrates that Octalysis's core drives, including empowerment, meaning, and ownership, are not only relevant but critical for sustaining user engagement. By mapping these motivational drives to specific game mechanics, the research bridges a gap between abstract gamification theory and its functional implementation in the built environment. In doing so, it offers an empirically grounded structure for understanding how intrinsic and extrinsic motivations converge in serious games aimed at social good.

The thesis also contributes to theory by providing empirical evidence of differential learning mechanisms between interactive and non-interactive media. Using multi-group SEM, it identifies distinct pathways of influence: while prior knowledge drives post-learning outcomes in game environments, usability and motivational appeal are more predictive in video-based learning. This dual-path discovery advances our theoretical comprehension of media-specific learning processes and highlights the moderating role of interactivity. Such findings refine existing cognitive and motivational models, suggesting that media affordances themselves shape learning pathways, thereby enriching our theoretical understanding of how digital media can be strategically designed to maximize educational impact.

Finally, the research contributes a taxonomy for serious games in air-quality education, synthesized from a systematic literature review of global studies. This taxonomy classifies prior work based on learning goals, game mechanics, user demographics, and technological platforms, establishing a foundational reference for future scholars investigating gamified environmental literacy. Collectively, these theoretical contributions deepen the understanding of how motivation, cognition, and interaction intersect within gamified systems. It offers a conceptual model that can be generalized beyond mold prevention to broader fields.

7.2.3 Practical Contributions

The findings of this research offer several practical implications for stakeholders involved in environmental health education and digital learning design. Overall, the results suggest that serious games should not be viewed merely as engagement tools but as structured learning environments whose effectiveness depends on pedagogical alignment, usability quality, and opportunities for reinforcement. Translating these insights into practice requires tailored actions from different professional groups.

For game designers, the results highlight the importance of prioritizing meaningful learning interaction over superficial gamification features. The observed advantage in knowledge retention within the game condition suggests that structured interactivity and timely feedback are central to learning durability. Designers should therefore focus on aligning gameplay tasks explicitly with learning objectives, implementing progressive challenge structures, and providing immediate formative feedback following user decisions. The findings also indicate the importance of managing cognitive load through clean interface design and avoiding unnecessary visual complexity. In the context of residential mold education, scenario-based simulations that reflect realistic household situations appear particularly valuable. Importantly, the results caution against over-reliance on points and rewards alone, as usability and instructional alignment emerged as more influential drivers of learning outcomes.

For educators and training providers, the study demonstrates that serious games can function effectively as complementary instructional tools, particularly for enhancing learner motivation and supporting longer-term knowledge retention. However, the comparable behavioral intention outcomes between the game and video conditions suggest that gameplay alone may not be sufficient to produce sustained behavioral change. In practice, serious games may be most effective when integrated into blended learning strategies that include guided reflection, facilitated discussion, or follow-up reinforcement activities. Educators may particularly benefit from deploying serious games with audiences who have low prior knowledge or limited engagement with traditional materials, as interactive scaffolding appears to support these learners more effectively. Positioning the game as a preparatory or reinforcement tool, rather than a standalone intervention, is likely to yield stronger educational impact.

For policymakers and housing authorities in New Zealand, the findings indicate that serious games represent a promising and scalable mechanism for public education on indoor air quality and mold prevention. Nevertheless, the evidence also suggests that digital education tools should be embedded within broader intervention ecosystems rather than implemented in isolation. Policymakers could consider incorporating validated serious games into Healthy Homes initiatives, tenant education programs, and public awareness campaigns. Supporting partnerships between researchers, public health agencies, and housing organizations will be important to ensure that educational content remains evidence-based and contextually relevant. At the same time, the results reinforce that awareness tools alone are unlikely to drive large-scale behavioral change without complementary structural improvements in housing quality and regulatory enforcement.

For health professionals and public health practitioners, the serious game developed in this research offers a practical resource for strengthening environmental health literacy among at-risk populations. Given the strong motivational and usability responses observed, interactive serious games may be particularly useful for engaging households that are less responsive to traditional brochures or verbal advice. Health practitioners could integrate serious game modules into asthma education programs, community outreach initiatives, and home health visits to help families better understand mold risks and prevention strategies. However, consistent with the behavioral findings of this study, professionals should monitor whether knowledge gains translate into actual household practices and consider pairing digital education with personalized guidance where possible.

7.3 Research Limitations

Despite its contribution, this research has several limitations that should be addressed in future research.

First, the experimental phase involved participants primarily recruited from the Auckland region using a convenience sampling approach. Although this provided a representative sample of the general public, the findings may not fully capture the experiences of individuals from other regions or cultural backgrounds within New Zealand. In future studies, expanding the sample to include more diverse demographic and geographic groups would strengthen the generalizability of the results.

Second, this study used validated instruments such as the IMI, TLX, NMSUS, and GSE to evaluate psychological constructs. However, these rely on self-reported perceptions, which may be subject to interpretation bias or temporary mood effects. While such measures are standard in educational psychology, combining them with observational or behavioral data in future work could offer a more comprehensive evaluation of learning outcomes.

Third, the serious game prototype was developed using *Articulate Storyline 360*, which provided a practical and accessible development platform but limited the inclusion of more immersive and interactive features such as adaptive feedback. Despite these constraints, the game effectively demonstrated how interactivity and motivational design enhance learning. Future improvements to the prototype could integrate higher-end technologies, such as virtual and augmented reality, to extend engagement and realism. Another notable limitation concerning the developed prototype lies in the selection of game elements and mechanics. Although these were primarily informed by the Octalysis framework and its application in previous studies, their selection was also influenced by somewhat subjective judgments regarding their perceived effectiveness. As such, the use of alternative elements or mechanics would result in a substantially different gameplay experience. This, in turn, would influence participants' performance across the evaluated measures (e.g., knowledge, self-efficacy, usability, etc.), potentially leading to either improved or diminished outcomes.

Fourth, the serious game and associated assessment instruments were delivered exclusively in English. While this reflects the dominant language of public communication in New Zealand, it may have influenced comprehension and engagement among participants who are non-native English speakers or who have limited English proficiency. Language barriers could potentially affect how instructions, feedback, and educational content are interpreted, thereby influencing measured learning outcomes. Future research should consider multilingual versions of the game and culturally responsive adaptations to ensure broader accessibility and to better reflect the linguistic diversity of New Zealand households.

Another limitation relates to the contextual specificity of the developed serious game. The educational content, scenarios, and environmental assumptions were deliberately designed around New Zealand housing conditions, climate patterns, and common residential practices. While this localization strengthens ecological validity within the New Zealand context, it may limit the direct transferability of the game to other climatic regions, housing typologies, or cultural settings. Differences in building construction, ventilation practices, occupant behavior, and climate-related moisture dynamics could influence both the relevance of the scenarios and the effectiveness of the intervention. Future research should therefore examine cross-context adaptation and validation of the game in different geographic and cultural environments to assess its broader applicability.

Last but not least, the retention period in this study was limited to four weeks, which offered valuable insights into short-term knowledge retention. As such, longer-term, longitudinal studies are needed to examine whether increased knowledge and motivation translate into sustained real-world behavioral change in household mold prevention.

7.4 Recommendations and Future Directions

The findings of this research reveal substantial potential for serious games as innovative and alternative educational approaches, particularly in the context of IAQ and mold prevention. However, several future directions are recommended to extend the scholarly, methodological, and societal impact of this work. These recommendations are organized around research development, technological advancement, scalability, and policy integration.

7.4.1 Research Development

Future research should aim to replicate and extend the present findings using larger, more diverse participant samples across different demographics, housing types, and cultural contexts. This would improve the generalizability and external validity of the results, particularly given the current study's controlled experimental setting. Longitudinal studies are also recommended to assess sustained behavioral change, not only immediately following the intervention but over several months or seasonal cycles, when mold-related conditions vary. Future experiments may incorporate objective indicators, such as environmental sensors or photographic evidence of user actions (e.g., improved ventilation, reduced humidity), to triangulate self-reported behavioral outcomes.

In addition, future research could move beyond cognitive outcomes to examine the actual behavioral impact of serious games. It would be valuable to investigate whether and how players apply the knowledge and skills acquired from the game in their everyday household practices and to identify the barriers and facilitators that influence the translation of learning into action. Understanding this knowledge–behavior gap is crucial, as individuals may recognize and comprehend recommended practices yet still fail to adopt them due to factors such as habit, perceived effort, social norms, or environmental constraints. Longitudinal and mixed-method approaches could provide deeper insights into the persistence of behavioral change over time and the contextual conditions that support or inhibit it.

Moreover, future studies could explore potential mediating variables that shape the effectiveness of serious games, such as emotional engagement, perceived realism, and social interaction. Employing advanced analytical techniques would enable the examination of time-based and contextual effects. Comparative studies could also test hybrid learning ecosystems that combine serious games with complementary technologies, including mobile reminders, augmented-reality simulations, or smart-home feedback systems. Such integrated digital environments would not only strengthen behavioral reinforcement but also help bridge the critical gap between awareness and sustained action toward healthier and more sustainable living.

7.4.2 Technological and Pedagogical Advancement

From a technological perspective, future versions of the serious game could benefit from greater interactivity and personalization. Adaptive algorithms may be incorporated into tailor difficulty levels, feedback, and learning pathways according to the learner's prior knowledge and self-efficacy levels. Incorporating 3D visualization, AR/VR immersion, or IoT data feeds could provide users with more dynamic and context-sensitive learning experiences. Pedagogically, the game can be expanded to support collaborative learning where users interact in simulated community environments to solve collective IAQ challenges, reinforcing social learning and peer engagement. To increase accessibility and inclusion, future development should explore multi-lingual interfaces, offline capability, and cross-platform functionality (mobile, tablet, and web-based). These improvements would enhance usability among diverse populations, including low-income or rural households where technological access may be limited. Embedding national design principles (e.g., Māori) and cultural narratives could also make the game more resonant and authentic.

7.4.3 Scalability and Implementation Potential

Future research could explore how the serious game developed in this study can be scaled and integrated into real-world educational and policy settings. One direction would be to examine its adoption through national and local initiatives such as governmental education campaigns, community health programs, or building performance schemes like *Warmer Kiwi Homes* and the *Healthy Homes Standards*. Further investigation should consider both barriers and enablers to large-scale implementation, with attention to accessibility, platform scalability, cultural adaptability, and cost-effectiveness across New Zealand's diverse communities. Collaboration with key stakeholders, including representatives from MBIE, BRANZ, Auckland Council, and public health agencies, would help identify the institutional, financial, and logistical factors that influence successful deployment. In addition, conducting a market feasibility or policy-alignment study could clarify potential pathways for commercialization, public licensing, or open-access dissemination.

Future studies might also examine how the game framework could be adapted to other environmental or sustainability topics such as ventilation literacy, energy efficiency behaviors, or moisture management. Exploring modular design updates, localized content, and gamified feedback mechanisms would support broader applications beyond mold prevention. Extending the platform in this way could transform it into a national digital infrastructure for environmental learning, capable of hosting multiple thematic modules and supporting community-wide education for healthier and more sustainable living.

7.4.4 Policy and Practice Integration

At the policy level, future work should focus on integrating game–based learning into national housing education strategies and community engagement programs. The findings underscore the need for evidence-based educational tools that complement regulatory frameworks with proactive, user-centered learning resources. The developed game, once scaled and refined, could be incorporated into the Healthy Homes certification process, energy audits, or school-based sustainability curricula. Collaborative partnerships between universities, government agencies, and community organizations would enable a sustainable pathway for implementation and evaluation. Finally, to ensure enduring societal impact, it is recommended that future initiatives establish monitoring and evaluation frameworks for measuring long-term behavioral and health outcomes resulting from serious game interventions. By embedding data analytics, periodic user assessments, and participatory design cycles, policymakers and researchers can ensure that these tools remain responsive, inclusive, and aligned with evolving public needs.

Ultimately, this thesis advances the built environment by shifting mold-prevention education from passive information dissemination to active experiential learning. It demonstrates that IAQ literacy can be strengthened not through warnings or leaflets, but through meaningful interaction, personal agency, and cognitive engagement. In doing so, this work offers an evidence-based blueprint for transforming public education on indoor health risks, empowering individuals to understand, anticipate, and prevent mold-related hazards in their own homes.

Appendix A: Summary of the eligible articles

Source	Q1	Q2	Q3		Q4	Q5	Q6	Q7	Q8
			Profile	N					
(Niemeyer et al., 2009)	IAP (Classrooms)	Educating on the impact of air pollution on the environment and how they can positively change their environment	High school students	37	Various roles and teams, social interactions, different in-game activities,	A wireless cell phone-based real-time air quality monitoring device	Overall positive feedback	N/A	John Dewey Theory: Play and Work in the Curriculum
(Leonardi et al., 2014)	IAP and OAP	To raise users' understanding of their general exposure to pollutants	Adults (parents of children aged zero to ten years)	80	Real-time feedback	A smartphone crowdsensing service containing environmental data and a web application to visualize the data	Curiosity was increased, leading to raising the citizen's motivation and awareness.	N/A	N/A
(Pokric et al., 2015)	IAP (General)	To teach users about air pollution and its effect on human health	Professional employees	23	Scores, choosing an avatar, points and awards, leaderboard	A non-immersive serious game application for smartphones, using real-time data monitoring	Positive feedback on simplicity for AR development, usability, available features and usage simplicity. It is reported that the game was entertaining	More tutorials are needed	N/A
(Carducci et al., 2016)	IAP and OAP (Virtual environment)	To promote knowledge about air pollution and air quality, health effects, policies against pollution, and healthy lifestyles	Primary school children	266	Storyboard, choose a player (boy or girl), multiple levels, score and score reduction, objectives	Cartoon and videogames for PC	The video games were useful, understandable, simple, fun, and educational for children. Children reported enjoying the games, with 60% stating that they learned something after playing. Additionally, pre- and post-assessments were conducted to measure changes in knowledge and perception. Post-assessment results showed a 1.40% improvement in knowledge related to educational activities	N/A	N/A
(Thomson et al., 2017)	Home IAQ monitoring (General)	To improve users' understanding of asthma clinical outcomes	Children aged seven to twelve years	4	Reminders, Feedback, Personalized character and avatar, Rewards and prizes, Task completion, answering questions, Secret code, Space locker, taking photos for postcards, Daily missions, Picking a name	A serious game involving a tablet application equipped with air quality monitors and spirometers	Users' engagement was improved; children rated the app as somewhat fun and helpful, but the exploration within the game was enjoyable	Non-portable air quality device has impacted on the gameplay features	N/A
(Grossman et al., 2017)	IAQ and asthma control (Home)	Encouraging the habit of daily asthma control to become routine behavior over time by educating them about the importance of air quality	Trainees aged eleven to sixteen years	12	Customizable avatar, scorecard, monetary award (to spend on Google Play), reminder, milestone or objective, dialogue box, rules, punishment, view their counterpart's score (like a competition), immediate feedback. Badge	A smartphone application integrating with a dose counter spirometer	N/A	Design limitation (positioning of the flashing light indicator and its visibility due to the plastic shell's opacity), lack of sturdiness of the dose counter, functional limitation occurring with rewards led to user frustration and mistrust due to unfulfilled app actions, communication errors between the dose counter and the app and the study faced a logistical limitation related to trainees' access to electricity	Captology and Elaboration Likelihood Model
(Bosello et al., 2020)	OAP (General)	To inform users about the importance of air quality and their exposure to air pollution	Adult	2	Motivations (fun and value), level and experience, achievements, registration and login, unlocking of achievements and position icons	A bicycle-based crowdsensing system, including real-time data collection with a web application for a smartphone	Positive users' engagement	N/A	N/A
(Teles et al., 2020)	OAP Visualizing (Virtual world)	To raise users' awareness of air pollution	Adults and young adults	30	Sitting on the bus as a passenger or by driving it, tasks, choosing different animated buses, tutorials, and help, two driving modes, text a non-text air pollution data visualization, teleport option	A serious game designed for laptops (plus keyboard and mouse), in which animated buses can trace the movements of real buses using GPS technology and collect real-time data based on the actual city plans and buildings configuration	Usage success rate, satisfactory task completion times, positive user experience, increased user engagement, and overall positive results about objective and subjective analysis	It lacks a rich narrative and a poor interface design	N/A

(Campana & Xavier Dominguez, 2020)	IAP visualization tool (General)	To increase users' awareness and understanding of air pollution as well as teach them about potential risks	Senior high school students	10	Filter options, information button, particles scale and risk buttons, rural, pause and play option	An immersive serious game for tablets or smartphones with real-time PM measurements	Usability and feasibility were confirmed, sparking curiosity and generating positive feedback	NA	N/A
(Varnavsky, 2020)	OAP (General)	To increase social responsibility in environmental processes on air pollution	Undergraduate student	70	N/A	A smartphone environmental application connecting to online environmental information about air pollution	Using smartphone environmental applications could increase trainees' social responsibility	N/A	N/A
(Delmas & Kohli, 2020)	IAP and OAP (General)	To educate on how to protect themselves against air pollution and promote changes in protective behavior	Ranged from eighteen to sixty-five years	99	Tomorrow's forecast, prize,	A smartphone application integrating with the real-time data collection device	User experience was positive, and the application increased their understanding of air pollution	N/A	Theory of Planned Behavior and the Theory of Issue Engagement
(Mahajan et al., 2020)	IAP and OAP (General)	To enhance users' understanding of air pollution	People ranged from eighteen to seventy-five years	25	Storytelling sessions, playing with the joystick-based console, collaboration,	Conventional technique: interactive web application air quality quizzes played with a computer or laptop with offline questionnaires and low-cost air quality monitoring sensors (+workshops)	The users' feedback regarding the tool was positive, awareness was raised, and the tools were engaging	N/A	NA
(Ling et al., 2021)	Monitoring IAQ	To promote users' knowledge about air pollution	Teenagers and youths	80	The editable main character, integrating a mini game	A serious game application for smartphones, including a sensor node for data collection	The feedback of willingness to use the application was positive by 60 % of the trainees.	NA	NA
(Relvas, 2021)	IAP and OAP (Virtual world)	To raise perception about air pollution and learn the possible causes of air pollution	Elementary students	20	The main character explains to the player Different non-player characters, Different game features, the Player's objectives, Dialogue, Guidance,	A serious game application for a laptop or PC	The post-assessment showed the children's perception was significantly improved.	Some bugs were appearing while playing the gameplay (the pause button did not work properly)	NA
(Shabanabegum et al., 2021)	IAP monitoring (Home)	To support users with asthma by monitoring and improving IAQ	Children aged eight to twelve years	12	Chatbot, List of action items (recommendations),	An application for smartphones	The children had little or no knowledge about IAP and how it affects their asthma.	NA	NA
(Kim et al., 2021)	IAP (Home)	To help users track their asthma condition and remind them about using a spirometer	Children aged eight to twelve years	12	Pick different emojis and personalized characters, track the history of the monitored information, provide Guidance, use Chatbot to answer questions,	Smartphone application with an IAQ sensor and a spirometer	NA	NA	NA
(Kim & Sohanchyk, 2022)	IAQ data visualization (Home)	To raise understanding about IAQ	Children aged seven to ten years	9	Suggests proper actions, an animated narrative cat	An application for tablets which consist of real-time IAQ data	Positive initial interaction and feedback, as well as parents' involvement, was increased	NA	NA
(S. Kim et al., 2022)	IAQ data visualization (Home)	To help users with asthma by improving IAQ	Children aged eight to twelve years	7	Chatbot, list of recommendation actions,	An application for smartphones interacting with real-time IAQ data	Initial impressions of the graphical interface were positive, and it was an effective tool for pediatric patients to check and confirm the source of an environmental asthma trigger. However, trainees reduced app use due to a lack of interactivity and fun.	NA	NA
(J. Fernandes et al., 2023)	IAP (Home, bedroom)	To improve users' knowledge about IAP	Elementary school children	27	Collaboration, Tutorial, Objectives, content, A non-playable character (to guide and hint), Scores and feedback, Users can choose the role,	A non-immersive serious game designed for laptops interacting with physical real-time sensor nodes	Results showed that knowledge was improved by about 50%. Satisfaction and usability and questionnaire of opinion and preference were also assessed	Technical issue related to AR implementation (tracking the markers)	NA

IAP: Indoor Air Pollution

Appendix B: Definition and usage of the retrieved game elements used within the eligible articles

Game elements (A to Q)	Definitions	Usage in the eligible papers	Sources
Narratives (A)	It offers players context about the games, providing a foundation to seamlessly introduce a compelling story (Chou, 2015, pp. 80-81).	*"An introductory video was shown to illustrate the main educational content of the games to the children."*	(Carducci et al., 2016, p. 250)
		"The scientist evaluates and explains to the player, via the main character, the possible causes regarding the air quality being displayed by each sensor placed in the several zones in the city" and "A set of dialogue teaching participants about pollution."	(Relvas, 2021, p. 16)
		"When we asked the participants to describe their experiences of using inAirKids during the early phase of the study, many dialogues were made from or reflected from the perspective of the animated cat on inAirKids."	(Kim & Sohanchyk, 2022, p. 6)
		"To guide the experience and reinforce its didactic content, a non-playable character (NPC) was created. The NPC was a scientist, graphically represented with sprites, who appears only in key moments of the experience."	(J. Fernandes et al., 2023, p. 13)
LevelUp (B)	This refers to a condition in which, once players level up, they can acquire a new set of skills while they are playing (Chou, 2015). Levelling up is an application linked to player progress within a game in which players earn or unlock incentives associated with each level once they have acquired the necessary experience points (McFarland, 2020, p. 117).	*"The first game was developed at multiple levels. The first level was set in the city."*	(Carducci et al., 2016, p. 252)
		"Unlocking of achievements and position icons according to distance travelled and point of interests visited."	(Bosello et al., 2020, p. 3)
Quest Lists (C)	Refers to a specific task, mission, or objectives players undertake in a game (Naraghi-Taghi-Off et al., 2020).	*"The child earns rewards for completing tasks and answering questions required by the clinical protocol."* And *"Fig. 6 describes some sample interactions of daily missions involving the 3 planets and these activities."*	(Thomson et al., 2017, pp. 3, 4)
		"...the in-game objectives and scoring system will induce the need to explore the remaining objects further to discover how to use them and which ones produce gases."	(J. Fernandes et al., 2023, p. 8)

		"...the "how to play" button, which shows a panel with text explaining what is happening in the city and the player's objectives."	(Relvas, 2021, p. 21)
		"The higher the intuitiveness of the tool, the better users can focus their cognitive effort on the primary task (e.g., planning the next vacations)..." and "Participants had to complete each task without being helped and without time limit,..."	(Teles et al., 2020, pp. 4, 12)
		"Other messages are displayed as encouragement when certain milestones are missed."	(Grossman et al., 2017, p. 54)
Step-by-Step Tutorial (D)	The tutorial is a feature that aids the learning process, giving instructive content in video games to familiarize players with the gameplay (Andersen et al., 2012; Cao & Liu, 2022).	*"To help the user exploring all available features...a set of embedded tutorials inspired by in-game tutorials is available, as well as a help button."*	(Teles et al., 2020, p. 9)
		"When beginning to play, participants also had a game tutorial to comprehend the controls and goals better when they started playing it."	(Relvas, 2021, p. 37)
		"...all apps offered informational content to encourage users to make beneficial, real-life changes."	(Kim et al., 2021, p. 5)
		"...a small tutorial presented at the beginning of the gaming experience..."	(J. Fernandes et al., 2023, p. 13)
Points (E)	Points refer to tokens that users can collect, which can be used as status indicators or to spend on virtual goods or gifting (Huang & Hew, 2015).	*"The collection of trees increase the user's score" and "The child with his avatar must collect the positive elements to increase the score..."*	(Carducci et al., 2016, p. 252)
		"The child earns rewards for completing tasks and answering questions required by the clinical protocol" and "Space Locker: the child was able to accumulate prizes and postcards from visiting alien worlds and store them in the space locker."	(Thomson et al., 2017, p. 3)
		"The closer the guess is, the more points are awarded."	(Pokric et al., 2015, p. 12)
		"The gamified experience comprises a scoring system, which rewards the user whenever gases or particles are directed to the window."	(J. Fernandes et al., 2023, p. 13)

		"The scorecard at the bottom of the screen is updated as soon as the app receives a transmission…depending on the scoring rules…"	(Grossman et al., 2017, p. 54)
Leaderboard (F)	It is a game element where you rank users based on a set of criteria influenced by the users' behaviors towards the Desired Actions. Even though Leaderboards are meant to motivate people and bring in status, if mis designed, they often do the exact opposite (Chou, 2015, p. 119).	*"…a high score leader board visible to all players is generated."*	(Pokric et al., 2015, p. 12)
Progress Bar (G)	A progress bar is a visual game mechanic representing a player's advancement toward a specific goal or task completion (Kosyakoff, 2024).	*"…all apps provided the features to track the history or trend of the monitored information."*	(Kim et al., 2021, p. 5)
Win Prize (H)	Win Prize refers to a gaming element where users or players can receive rewards or incentives upon achieving a specific goal, completing a challenge, or reaching a designated level of accomplishment within the game (Chou, 2015).	*"In the initial design, the participant was given a monetary award of $0.50, which was later changed to $1.00 to better motivate users. The amount was added to the scores on the trading card…"*	(Grossman et al., 2017, p. 55)
		"…a prize tab that incentivizes people to respond to daily survey questions…"	(Delmas & Kohli, 2020, p. 284)
Instant Feedback (I)	In gamification, feedback refers to the immediate and visible responses users receive from other users or experts, raising a sense of encouragement. This instant feedback mechanism intuitively enhances the user's perception of success and accomplishment (Chou, 2015).	*"The application is configured as an Android widget and provides real-time feedback with three layouts."*	(Leonardi et al., 2014, p. 1052)
		"This intends to be a simple way of providing feedback and assigning tasks to users, encouraging them to…"	(J. Fernandes et al., 2023, p. 13)
		"Aspira allows families to continuously monitor indoor air quality on their own…" and "*We expect the real-time, objective feedback about indoor air quality to overcome knowledge barriers…*"	(Thomson et al., 2017, p. 1)
		"This immediate positive feedback of scoring a basket and receiving $0.50 to spend at the Google Play store motivated them to…"	(Grossman et al., 2017, p. 55)
		" a chatbot placed at the bottom left corner of the navigation bar. It answers questions regarding air quality and asthma in…"	(Kim et al., 2021, p. 6)
		"a chatbot to ask any question relating to IAQ and asthma management…"	(S. Kim et al., 2022, p. 3)

Choice Perception (J)	Choice Perception is the tendency for individuals to feel more intrinsically motivated when presented with multiple options or choices, emphasizing the positive impact of perceived alternatives on motivation (Iyengar & Lepper, 2000).	*"…we provided a list of action items that the user can perform to improve IAQ."*	(Shabanabegum et al., 2021, p. 7117)
		"Once they arrive at the game location, users choose the role they will play in the experience…"	(J. Fernandes et al., 2023, p. 14)
		"The user can also choose to ride one of the animated city buses, allowing the user to effortlessly move across the city…"	(Teles et al., 2020, p. 4)
		"…we provided a list of recommended actions that the user can take to improve the IAQ."	(S. Kim et al., 2022, p. 3)
Boosters (K)	Boosters in a game, where players obtain something to help them achieve the win-state effectively (Chou, 2015, p. 145).	*"…a "secret code" the child obtained to facilitate space travel."*	(Thomson et al., 2017, p. 3)
Avatar (L)	It is a graphical representation or character representing a user within the game or online platform. Avatars can be customized to reflect the user's preferences, allowing them to personalize their virtual identity (Szolin et al., 2023).	*"The game is focused around avatar that the user selects at the start of the game. The avatar can be visualized through the AR view once the appropriate markers are detected."*	(Pokric et al., 2015, p. 12)
		"To increase the children's participation, they could choose either a boy or girl as a player."	(Carducci et al., 2016, p. 252)
		"The space-themed game involves a personalized character, or avatar,…"	(Thomson et al., 2017, p. 4)
		"…presenting an interactive and customizable avatar…"	(Grossman et al., 2017, p. 54)
		"…the apps for asthma management allowed users to pick different emojis and other colored graphical components…" and "…all apps used graphic characters and personified graphical components to make information more engaging and fun…"	(Kim et al., 2021, p. 5)
Group Quest (M)	This feature is very effective in collaborative play as well as viral marketing because it requires group participation before any individual can achieve the Win-State (Chou, 2015, p. 219).	*"…it is also a useful depiction of individual and group dynamics within the game."*	(Niemeyer et al., 2009, p. 1079)
		"The main idea is to provide an environment where communities and scientists can collaborate towards a common goal that further leads to community capacity building."	(Mahajan et al., 2020, p. 3)

		"The game was designed to be a cooperative multi-player, building upon the identified advantages of collaboration over competition in educational contexts."	(J. Fernandes et al., 2023, p. 6)
Social Invite/Friending (N)	This mechanism encourages players to connect with others, raising a sense of community, and often provides in-game benefits or collaborative opportunities tied to having a network of friends (Consalvo, 2011).	*"Participants were forced to research the lights, and, upon discovery, share the information through social interaction."*	(Niemeyer et al., 2009, p. 1075)
Visual Storytelling (O)	Storytelling conveys events through words, sound, or images, serving various purposes. It includes oral traditions and techniques across different media to unfold narratives (Giakalaras, 2016).	*"The storytelling sessions provided citizens a platform tonclearly present their overall experience by contextualizing the story i.e. identifying the aim,…"*	(Mahajan et al., 2020, p. 3)
		"…the scientist evaluates and explains to the player, via the main character, the possible causes regarding the air quality…"	(Relvas, 2021, p. 16)
Progress Loss (P)	It is a game element where players experience setbacks by losing their in-game progress or achievements. This element often serves as a consequence for failure or certain in-game events, adding challenge and strategic considerations to the gaming experience (Chou, 2015).	*"…the negative elements that reduce the score and block the game for 5 s."*	(Carducci et al., 2016, p. 252)
		"If the medicine is taken outside the prescribed time window, a message is displayed informing them that they missed their medication time and that they cannot receive a reward."	(Grossman et al., 2017, p. 54)

Appendix C: Human Ethics, Information Sheets, and Consent Forms

(For interview)

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

19/08/2024

Dear: Armin Baghaei Daemei

Re: Low Risk Notification - 4000028748 - Focus Group to Validate the Application of Gamification for Indoor Air Quality Education in Residential Buildings in New Zealand

Thank you for submitting a low risk notification for your research/teaching/evaluation.

This email is to acknowledge receipt of the low risk notification and to inform you that the details of your project have been recorded in our database for inclusion in the annual reports to the Health Research Council Ethics Committee (HRCEC) and the Massey University Research Committee (URC).

You may proceed with your research, though it is advisable to provide a couple of weeks before commencing, as all low risk notifications are checked for completeness and clarity by a Research Ethics Advisor. You may be contacted if your application is incomplete and/or further clarification is required.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis.

If a sponsoring organisation, funding authority (e.g., the Health Research Council) or a journal require evidence of ethical approval from a Human Ethics Committee (with an approval number), you need to complete a full Massey University Human Ethics application to be reviewed and approved by one of our Human Ethics Committees. Applications must be submitted and approved prior to the commencement of the research.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact the Research Ethics Office, email humanethics@massey.ac.nz. "

Please include the following statement on all public documents (e.g., information sheet, consent form) related to your project:

> ***This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.***
>
> ***If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz.***

I wish you all the best in your research, teaching or evaluation activities and appreciate your thoughtful consideration of ethics principles and practices.

Ngā mihi nui,

Professor Tracy Riley
Acting Chair, Research Ethics Chair's Committee

Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand T 06 951 6841; 06 951 6840
E humanethics@massey.ac.nz; animalethics@massey.ac.nz; gtc@massey.ac.nz

(For home visit)

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

2/12/2024

Dear: Abdollah Baghaei Daemei

Re: Low Risk Notification - 4000029998 - Validating the serious game educational content on mold in residential buildings

Thank you for submitting a low risk notification for your research/teaching/evaluation.

This email is to acknowledge receipt of the low risk notification and to inform you that the details of your project have been recorded in our database for inclusion in the annual reports to the Health Research Council Ethics Committee (HRCEC) and the Massey University Research Committee (URC).

You may proceed with your research, though it is advisable to provide a couple of weeks before commencing, as all low risk notifications are checked for completeness and clarity by a Research Ethics Advisor. You may be contacted if your application is incomplete and/or further clarification is required.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis.

If a sponsoring organisation, funding authority (e.g., the Health Research Council) or a journal require evidence of ethical approval from a Human Ethics Committee (with an approval number), you need to complete a full Massey University Human Ethics application to be reviewed and approved by one of our Human Ethics Committees. Applications must be submitted and approved prior to the commencement of the research.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact the Research Ethics Office, email humanethics@massey.ac.nz. "

Please include the following statement on all public documents (e.g., information sheet, consent form) related to your project:

> ***This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.***
>
> ***If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz.***

I wish you all the best in your research, teaching or evaluation activities and appreciate your thoughtful consideration of ethics principles and practices.

Ngā mihi nui,

Professor Tracy Riley
Acting Chair, Research Ethics Chair's Committee

Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand T 06 951 6841; 06 951 6840
E humanethics@massey.ac.nz; animalethics@massey.ac.nz; gtc@massey.ac.nz

(For the main experiment)

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

6/03/2025

Dear: Abdollah Baghaei Daemei

Re: Low Risk Notification - 4000030296 - Assessing the effectiveness of a serious game compared to video training on mold prevention in residential buildings

Thank you for submitting a low risk notification for your research/teaching/evaluation.

This email is to acknowledge receipt of the low risk notification and to inform you that the details of your project have been recorded in our database for inclusion in the annual reports to the Health Research Council Ethics Committee (HRCEC) and the Massey University Research Committee (URC).

You may proceed with your research, though it is advisable to provide a couple of weeks before commencing, as all low risk notifications are checked for completeness and clarity by a Research Ethics Advisor. You may be contacted if your application is incomplete and/or further clarification is required.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis.

If a sponsoring organisation, funding authority (e.g., the Health Research Council) or a journal require evidence of ethical approval from a Human Ethics Committee (with an approval number), you need to complete a full Massey University Human Ethics application to be reviewed and approved by one of our Human Ethics Committees. Applications must be submitted and approved prior to the commencement of the research.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

If you have any concerns about the conduct of this research that you want to raise with someone other than the researcher(s), please contact the Research Ethics Office, email humanethics@massey.ac.nz. "

Please include the following statement on all public documents (e.g., information sheet, consent form) related to your project:

> ***This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.***
>
> ***If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz.***

I wish you all the best in your research, teaching or evaluation activities and appreciate your thoughtful consideration of ethics principles and practices.

Ngā mihi nui,

Professor Tracy Riley
Acting Chair, Research Ethics Chair's Committee

Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand T 06 951 6841; 06 951 6840
E humanethics@massey.ac.nz; animalethics@massey.ac.nz; gtc@massey.ac.nz

(INTERVIEW)

School of Built Environment
College of Science

School of Built Environment
Quadrangle Building A
Albany campus, Auckland 0632
New Zealand

INFORMATION SHEET

Name of Principal Researcher: **Abdollah Baghaei Daemei**
Research Project Title: **Validate the Application of Gamification for Indoor Air Quality Education in Residential Buildings in New Zealand**

You are invited to take part in this research. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to participate, thank you for considering this request. My name is Abdollah Baghaei Daemei and I am PhD Candidate in the School of Built Environment at the Massey University. This research project is work towards my PhD dissertation.

Purpose of this Participant Information Sheet (PIS)
The purpose of this Participant Information Sheet (PIS) is to provide you with detailed information about the research study aimed at validating the educational content used in a serious game designed to teach mold prevention in residential buildings by gathering expert feedback on the content.

Research Summary
This interview is designed to validate the content of a serious game aimed at teaching mold prevention in residential buildings by gathering technical feedback from experts. Initially, we compiled essential educational content from major open-access New Zealand building codes, regulations, and relevant websites concerning mold assessment, including causes, strategies, and optimal temperature and humidity ranges. To move forward, we need expert feedback on the suitability of this content and the effectiveness of our gamification techniques. The interview will be conducted in person, with an online option via Zoom or Microsoft Teams if necessary. It will last between 2 to 3 hours, with data collected through video recording, audio recording, and note-taking. All data will be securely stored on Massey University's OneDrive, solely for research purposes. Ethical approval has been obtained, and participant confidentiality will be strictly maintained. We aim to have 8 to 12 participants, ideally from the New Zealand Indoor Air Quality Research Center, BRANZ, NIWA, or other relevant organizations, chosen for their expertise in indoor air quality and mold prevention. The session will take place at the Massey University Auckland Campus. The group will be moderated by the main supervisor and the student researcher.

How can you help?
Your participation is essential to the success of this reserach. By joining our interview, you will help shape the development of a serious game. We are seeking your feedback on to make sure whether something is missing or not.

Participation and withdrawal:

Participation in this interview is completely voluntary. You are free to decide whether or not to take part in this study. If you choose to participate, you are free to withdraw at any time without any penalty or loss of benefits to which you are otherwise entitled. Your decision to withdraw will not affect your relationship with Massey University or any other associated institutions. If you decide to withdraw, please inform the researcher, and your data will be excluded from the study if requested.

Data Collection & Data Management:

The data for this research will be collected through a semi-structured questionnaire administered during the interview session. The interview will explore participants' experiences and opinions on the educational content of the game. All data collected will be handled with strict confidentiality. Your responses and any recorded audio/video will be anonymized, and any identifying information will be removed to protect your privacy. Only the principal researcher and authorized members of the research team will have access to the raw data (such as audio and video recordings). You will be able to withdraw your data should you no longer wish to participate, up to the point of data analysis. Should you wish to withdraw, you will need to notify the researchers prior to data analysis, and your data will be deleted immediately. Participants will have access to the transcripts and can amend the content up to one week after the interview.

Confidentiality and Anonymity:

Confidentiality is of the upmost importance in all stages of this research. All data will be identified. This will include the removal of any names or other potentially identifying information you may mention in the interview. No individual data will be described or released in any form, and only aggregate data will be presented in any reports based on this data. If you are an employee of this organization, your employer has given permission for employees to take part but, will not be notified of your specific participation andwill not be provided with individual employee data.

Queries

Any queries or concerns regarding the research project can be addressed by contacting:

Researcher: Abdollah Baghaei Daemei
Phone: +64 [redacted]
E-mail: abaghaei@massey.ac.nz

Supervisor: Dr Zhenan Feng
Phone: +64 92136194
E-mail: z,feng1@massey.ac.nz

Supervisor: Dr Daniel Paes
Phone: +64 [redacted]
E-mail: d.paes@massey.ac.nz

This project has been reviewed and approved by the Massey University Human Ethics Ohu Matatika 1, Application 4000028748 (attached here). If you have any concerns about the conduct of this research, please contact the Chairperson, Massey University Human Ethics Ohu Matatika 1, email humanethics1@massey.ac.nz

(HOME VISIT)

School of Built Environment
College of Science

TE KUNENGA KI PŪREHUROA | MASSEY UNIVERSITY
UNIVERSITY OF NEW ZEALAND

School of Built Environment
Quadrangle Building A
Albany campus, Auckland 0632
New Zealand

INFORMATION SHEET

Name of Principal Researcher: **Abdollah Baghaei Daemei**
Research Project Title: **Validating the serious game educational content on mold in residential buildings**

You are invited to take part in this research. Please read this information before deciding whether or not to take part. If you decide to participate, thank you. If you decide not to participate, thank you for considering this request. My name is Abdollah Baghaei Daemei and I am PhD Candidate in the School of Built Environment at the Massey University. This research project is work towards my PhD dissertation.

Purpose of this Participant Information Sheet (PIS)
The purpose of this Participant Information Sheet (PIS) is to provide you with detailed information about the research study aimed at Validating the serious game educational content on mold in residential buildings by collecting some pictures from the mold prone areas in residential buildings.

Research Summary
This research aims to validate the content of a serious game designed to teach mold prevention in residential buildings. A key aspect involves capturing evidence-based photographs of mold-prone areas to enhance the game's educational value. The content was developed using New Zealand building codes, regulations, and publicly available resources on mold assessment. Expert feedback from semi-structured interviews informed the content, and the next phase involves home visits to evaluate its relevance and the effectiveness of gamification techniques.
Home visits will focus on photographing mold-prone areas in kitchens, bedrooms, and bathrooms, while avoiding personal spaces or items. Participants will be recruited door-to-door by asking if they have experienced mold in their house. Eligible participants will either identify mold-prone areas or take photographs of moldy spots. There are no strict eligibility criteria, as mold can occur in any house across New Zealand, but only standalone houses will be included.
Participants will be fully informed of the study's purpose, and written consent will be obtained prior to data collection. Photographs will avoid identifiable features, and all data will be securely stored on Massey University's OneDrive for research purposes only. Participants will be asked to confirm the use of their images via email within two weeks, with one reminder sent midway. If no response is received, consent will be considered granted. This process ensures that the game content reflects real-world conditions, enhancing its educational impact. The data collected will validate findings from prior focus group research. Images used in the study will have personal details removed to protect participant privacy.

How can you help?
Your participation is essential to the success of this reserach. By joining our interview, you will help shape

the development of a serious game. We are seeking your feedback on to make sure whether something is missing or not.

Participation and withdrawal:
Participation in this interview is completely voluntary. You are free to decide whether or not to take part in this study. If you choose to participate, you are free to withdraw at any time without any penalty or loss of benefits to which you are otherwise entitled. Your decision to withdraw will not affect your relationship with Massey University or any other associated institutions. If you decide to withdraw, please inform the researcher, and your data will be excluded from the study if requested.

Data Collection & Data Management:
The data for this research will be collected through a semi-structured questionnaire administered during the interview session. The interview will explore participants' experiences and opinions on the educational content of the game. All data collected will be handled with strict confidentiality. Your responses and any recorded audio/video will be anonymized, and any identifying information will be removed to protect your privacy. Only the principal researcher and authorized members of the research team will have access to the raw data (such as audio and video recordings). You will be able to withdraw your data should you no longer wish to participate, up to the point of data analysis. Should you wish to withdraw, you will need to notify the researchers prior to data analysis, and your data will be deleted immediately. Participants will have access to the transcripts and can amend the content up to one week after the interview.

Confidentiality and Anonymity:
Confidentiality is of the upmost importance in all stages of this research. All data will be identified. This will include the removal of any names or other potentially identifying information you may mention in the interview. No individual data will be described or released in any form, and only aggregate data will be presented in any reports based on this data. If you are an employee of this organization, your employer has given permission for employees to take part but, will not be notified of your specific participation andwill not be provided with individual employee data.

Queries
Any queries or concerns regarding the research project can be addressed by contacting:

Researcher: Abdollah Baghaei Daemei
Phone: +64[redacted]
E-mail: abaghaei@massey.ac.nz

Supervisor: Dr Zhenan Feng
Phone: +64 92136194
E-mail: z,feng1@massey.ac.nz

Supervisor: Dr Daniel Paes
Phone: +64[redacted]
E-mail: d.paes@massey.ac.nz

This project has been reviewed and approved by the Massey University Human Ethics Ohu Matatika 1, Application 4000028748 (attached here). If you have any concerns about the conduct of this research, please contact the Chairperson, Massey University Human Ethics Ohu Matatika 1, email humanethics1@massey.ac.nz

(MAIN EXPERIMENT)

School of Built Environment
College of Science

TE KUNENGA KI PŪREHUROA | MASSEY UNIVERSITY
UNIVERSITY OF NEW ZEALAND

School of Built Environment
Quadrangle Building A
Albany campus, Auckland 0632
New Zealand

INFORMATION SHEET

Name of Principal Researcher: **Abdollah Baghaei Daemei**
Research Project Title: **Assessing the effectiveness of a serious game compared to video training on mold prevention in residential buildings**

You are invited to participate in a research study that aims to compare two different educational methods—a serious game and video training—to teach individuals how to prevent mold growth in residential buildings. The goal is to understand which method is more effective in improving knowledge and promoting behavioral change. If you decide to participate, thank you. If you decide not to participate, thank you for considering this request. My name is Abdollah Baghaei Daemei and I am PhD Candidate in the School of Built Environment at the Massey University. This research project is work towards my PhD dissertation.

Purpose of this Participant Information Sheet (PIS)
This research aims to assess the effectiveness of a serious game designed at educating individuals on how to prevent mold growth in residential buildings in New Zealand by comparing in with video training as a conventional approach.

What Will You Need to Do?
If you choose to participate, you will be randomly assigned to one of two training groups:

1. Game-Based Training: You will interact with a serious game that teaches mold prevention strategies.
2. Video-Based Training: You will watch an instructional video on mold prevention.

The study involves three main steps:

1. Pre-Test (5 minutes): Answer a short questionnaire about your general knowledge of mold prevention.
2. Training (15-20 minutes): Engage with either the serious game or video training.
3. Post-Test (5 minutes): Complete another questionnaire to assess what you have learned.

Additionally, four weeks later, you will receive an email with a follow-up questionnaire to measure how much of the information you have retained.

How Long Will It Take?
The entire session will take approximately 30 minutes, plus a short follow-up questionnaire after four weeks (around 5 minutes).

Incentive
As a thank-you for your time, you will receive a $10 voucher after completing the study.
How can you help?
Your participation is essential to the success of this reserach. By joining our interview, you will help shape the development of a serious game. We are seeking your feedback on to make sure whether something is missing or not.

Participation and withdrawal:
Participation in this interview is completely voluntary. You are free to decide whether or not to take part in this study. If you choose to participate, you are free to withdraw at any time without any penalty or loss of benefits to which you are otherwise entitled. Your decision to withdraw will not affect your relationship with Massey University or any other associated institutions. If you decide to withdraw, please inform the researcher, and your data will be excluded from the

study if requested.

Data Collection & Data Management:
The data for this research will be collected through a semi-structured questionnaire administered during the interview session. The interview will explore participants' experiences and opinions on the educational content of the game. All data collected will be handled with strict confidentiality. Your responses and any recorded audio/video will be anonymized, and any identifying information will be removed to protect your privacy. Only the principal researcher and authorized members of the research team will have access to the raw data (such as audio and video recordings). You will be able to withdraw your data should you no longer wish to participate, up to the point of data analysis. Should you wish to withdraw, you will need to notify the researchers prior to data analysis, and your data will be deleted immediately. Participants will have access to the transcripts and can amend the content up to one week after the interview.

Confidentiality and Anonymity:
Confidentiality is of the upmost importance in all stages of this research. All data will be identified. This will include the removal of any names or other potentially identifying information you may mention in the interview. No individual data will be described or released in any form, and only aggregate data will be presented in any reports based on this data. If you are an employee of this organization, your employer has given permission for employees to take part but, will not be notified of your specific participation andwill not be provided with individual employee data.

Queries
Any queries or concerns regarding the research project can be addressed by contacting:

Researcher: Abdollah Baghaei Daemei
Phone: +64 [redacted]
E-mail: abaghaei@massey.ac.nz

Supervisor: Dr Zhenan Feng
Phone: +64 92136194
E-mail: z,feng1@massey.ac.nz

Supervisor: Dr Daniel Paes
Phone: +64 [redacted]
E-mail: d.paes@massey.ac.nz

This project has been evaluated by peer review and judged to be low risk (notification number: 4000030296). Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research. If you have any concerns about the ethical conduct of this research that you want to raise with someone other than the researcher(s), please contact Massey University Human Ethics by email: humanethics@massey.ac.nz.

School of Built Environment
College of Science

School of Built Environment
Quadrangle Building A
Albany campus, Auckland 0632
New Zealand

Focus Group to Validate the Application of Gamification for Indoor Air Quality Education in Residential Buildings in New Zealand

FOCUS GROUP PARTICIPANT CONSENT FORM

I have read, or have had read to me in my first language, and I understand the Information Sheet attached as Appendix I. I have had the details of the study explained to me, my questions have been answered to my satisfaction, and I understand that I may ask further questions at any time. I have been given sufficient time to consider whether to participate in this study and I understand participation is voluntary and that I may withdraw from the study at any time.

1. I understand that I have an obligation to respect the privacy of the other members of the group by not disclosing any personal information that they share during our discussion.
2. I understand that all the information I provide will be kept confidential to the extent permitted by law, and the names of all people in the study will be kept confidential by the researcher.

Note: *There are limits on confidentiality as there are no formal sanctions on other group participants from disclosing your involvement, identity or what you say to others in the focus group. There are risks in taking part in focus group research and taking part assumes that you are willing to assume those risks.*

3. I agree to participate in the focus group under the conditions set out in the Information Sheet attached as Appendix I.

Declaration by Participant:

I ___________________________________ hereby consent to take part in this study.

Signature: ______________________ **Date:** _______________

School of Built Environment
College of Science

TE KUNENGA KI PŪREHUROA | MASSEY UNIVERSITY
UNIVERSITY OF NEW ZEALAND

School of Built Environment
Quadrangle Building A
Albany campus, Auckland 0632
New Zealand

Validating the serious game educational content on mold in residential buildings

FOCUS GROUP PARTICIPANT CONSENT FORM

I have read, or have had read to me in my first language, and I understand the Information Sheet attached as Appendix I. I have had the details of the study explained to me, my questions have been answered to my satisfaction, and I understand that I may ask further questions at any time. I have been given sufficient time to consider whether to participate in this study and I understand participation is voluntary and that I may withdraw from the study at any time.

1. I understand that I have an obligation to respect the privacy of the other members of the group by not disclosing any personal information that they share during our discussion.
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Note: *There are limits on confidentiality as there are no formal sanctions on other group participants from disclosing your involvement, identity or what you say to others in the focus group. There are risks in taking part in focus group research and taking part assumes that you are willing to assume those risks.*

3. I agree to participate in the focus group under the conditions set out in the Information Sheet attached as Appendix I.

Declaration by Participant:

I ___________________________________ hereby consent to take part in this study.

Signature: _______________________ **Date:** ________________

School of Built Environment
College of Science

TE KUNENGA KI PŪREHUROA | MASSEY UNIVERSITY
UNIVERSITY OF NEW ZEALAND

School of Built Environment
Quadrangle Building A
Albany campus, Auckland 0632
New Zealand

Assessing the effectiveness of a serious game compared to video training on mold prevention in residential buildings

PARTICIPANT CONSENT FORM

I have read, or have had read to me in my first language, and I understand the Information Sheet attached as Appendix I. I have had the details of the study explained to me, my questions have been answered to my satisfaction, and I understand that I may ask further questions at any time. I have been given sufficient time to consider whether to participate in this study and I understand participation is voluntary and that I may withdraw from the study at any time.

1. I understand that I have an obligation to respect the privacy of the other members of the group by not disclosing any personal information that they share during our discussion.
2. I understand that all the information I provide will be kept confidential to the extent permitted by law, and the names of all people in the study will be kept confidential by the researcher.

Note: There are limits on confidentiality as there are no formal sanctions on other group participants from disclosing your involvement, identity or what you say to others in the study. There are risks in taking part in this research and taking part assumes that you are willing to assume those risks.

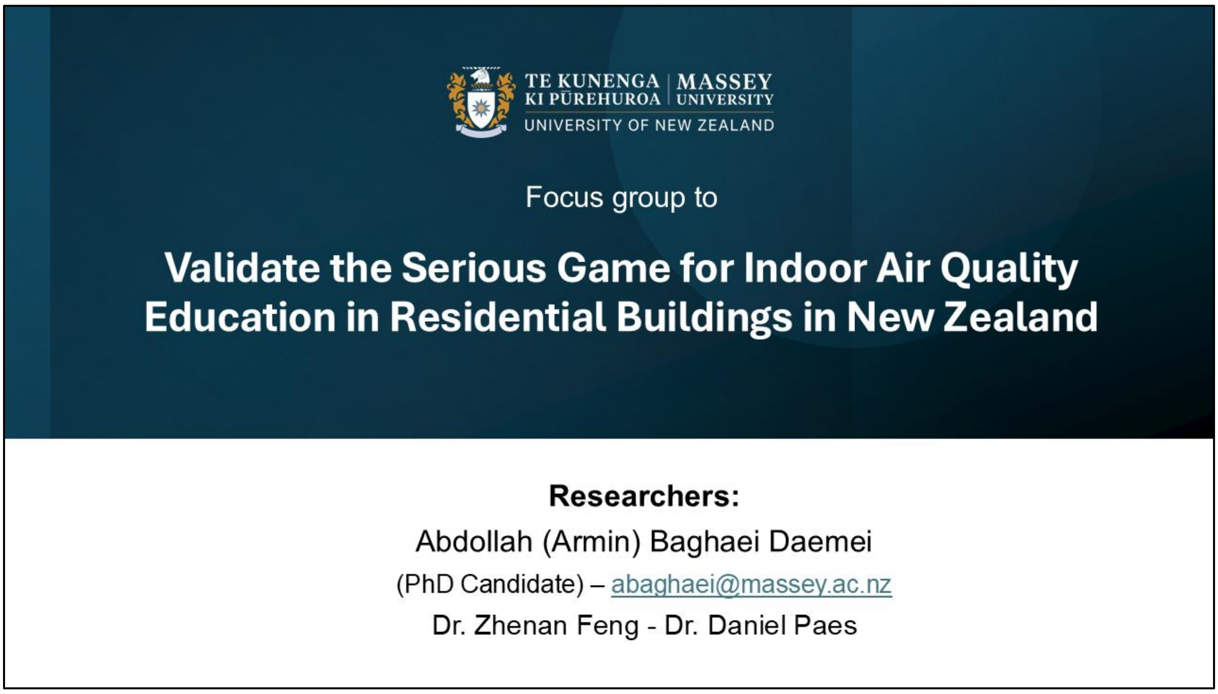
3. I agree to participate in this study under the conditions set out in the Information Sheet attached as Appendix I.

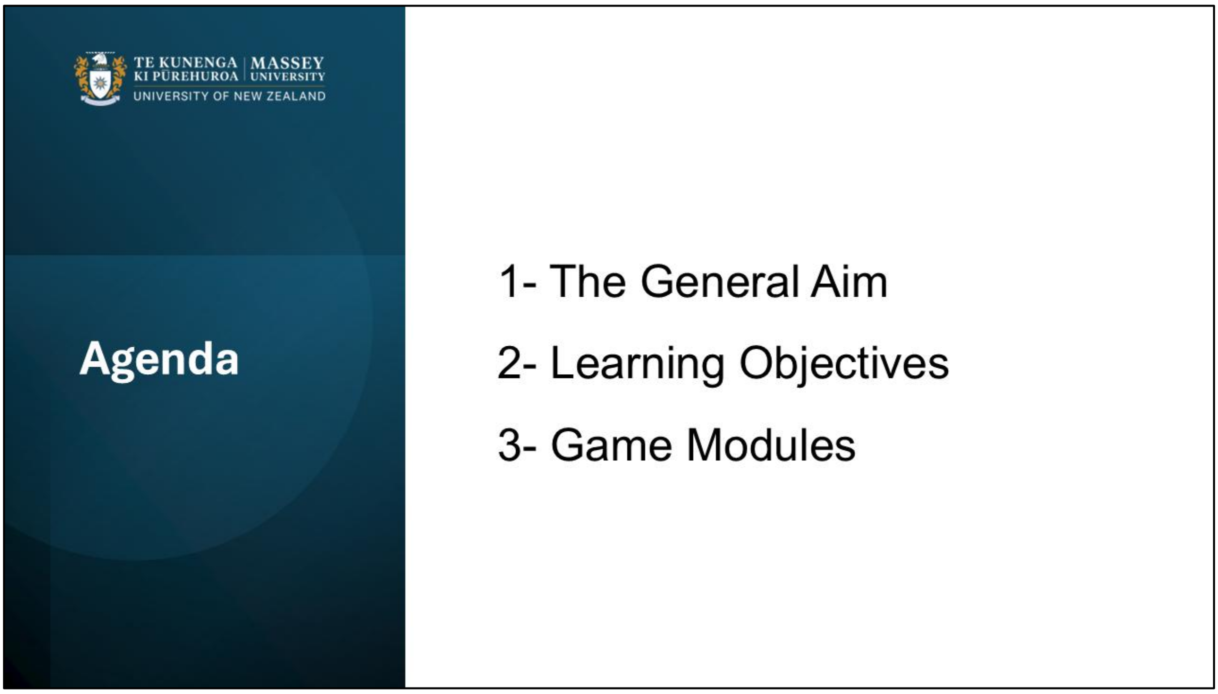
Declaration by Participant:

I ___________________________________ hereby consent to take part in this study.

Signature: ______________________ **Date:** ________________

Appendix D: Semi-structured Interview Questions and Slides





The General Aim

The aim of this interview is to validate the serious game designed to teach mold prevention in residential buildings by gathering experts' feedback and explore perceptions on the game.

Learning Objectives

There are four LOs:

LO1: Identify the specific spots in the kitchen, bedroom, and bathroom where mold is likely to grow.
LO2: Recall the essential elements required for mold formation, including temperature, humidity, spores, and nutrients.
LO3: Understand the conditions of temperature and humidity for mold growth.
LO4: Apply strategies to prevent mold growth in residential buildings.

Game Modules

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Level 1 → Level 2 → Level 3 → Level 4

LO 1 | LO 2 | LO 3 | LO 4

LO1: Identify the specific spots in the kitchen, bedroom, and bathroom where mold is likely to grow.
LO2: Recall the essential elements required for mold formation, including temperature, humidity, spores, and nutrients.
LO3: Understand the conditions of temperature and humidity for mold growth.
LO4: Apply strategies to prevent mold growth in residential buildings.

Game modules

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Game modules (M1)

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What: Users will learn to identify and understand the specific spots in different rooms where mold is likely to occur.

How: By identifying different spots in the kitchen, bedroom, and bathroom through an interactive activity, such as selecting spots in these rooms where mold is likely to grow based on given conditions.

Game modules (M1)

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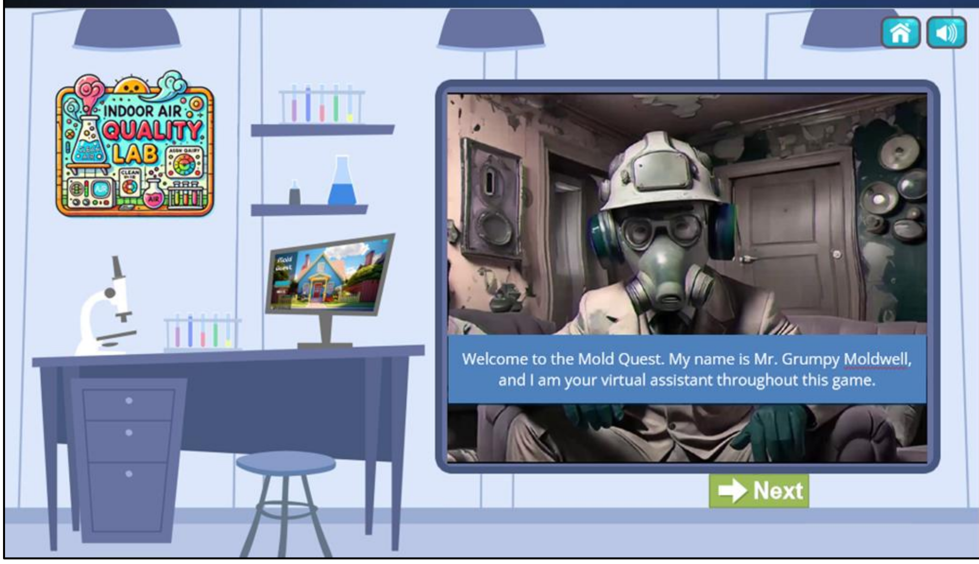

Game modules (M1)

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Kitchen:

Correct Spots

1- Windowsill
2- Ceiling corner
3- Under the sink
4- Near the trash can

Incorrect Spots

6- Centre of ceiling
7- Upper cabinets
8- Top of the range hood
9- Near the stove
10- Behind the refrigerator
11- Inside the oven
12- Countertops

Game modules (M1)

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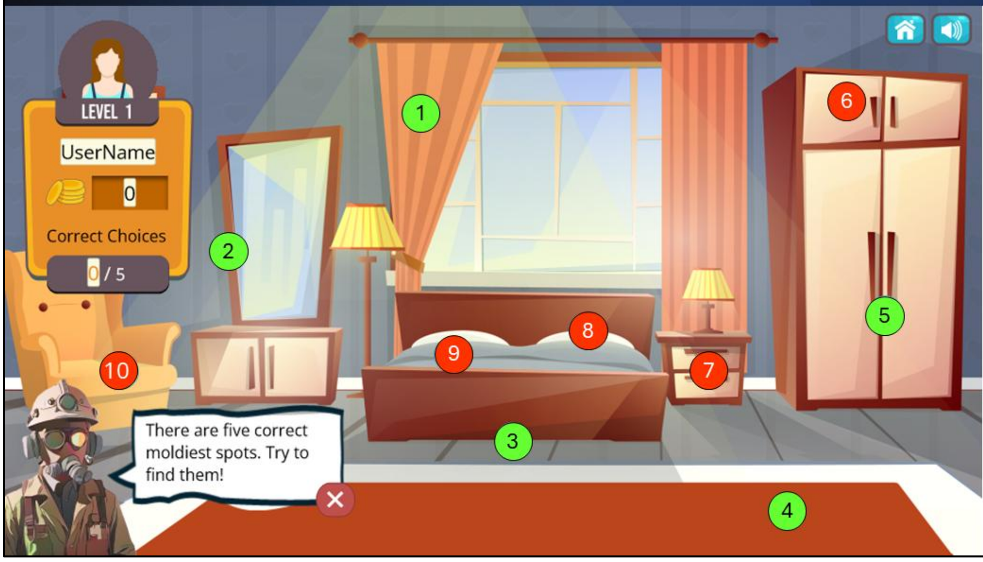

Bedroom:

Correct Spots

1- Windowsill
2- Behind the wardrobes
3- Under the bed
4- Under the carpet
5- Inside the wardrobes

Incorrect Spots

6- Top of the closet
7- Inside the bedside
8- Under the pillow
9- Bedspread
10- Under the furniture

Game modules (M1)

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Bathroom:

Correct Spots

1- On the shower glass
2- Around the shower or bathtub
3- On grout and tiles
4- Around the wash basin
5- Ceiling corner
6- Behind the toilet

Incorrect Spots

7- Towel rack
8- On the mirror
9- Toothbrush holder
10- Around the washing machine

Game modules (M1)

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Questions:

- Do you think the activities accurately represent common mold-prone areas in kitchens, bedrooms, and bathrooms?
- Apart from kitchen, bedroom, and bathroom, do you think we should develop other spaces in this game? (e.g. lounge etc.)
- Are there any important spots for mold growth that we might have overlooked?

Game modules (M2)

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What: Users will learn and recall the key elements necessary for mold to form.

How: By engaging in a multiple-choice quiz activity that challenges users to correctly select the four essential elements from various options.

Game modules (M2)

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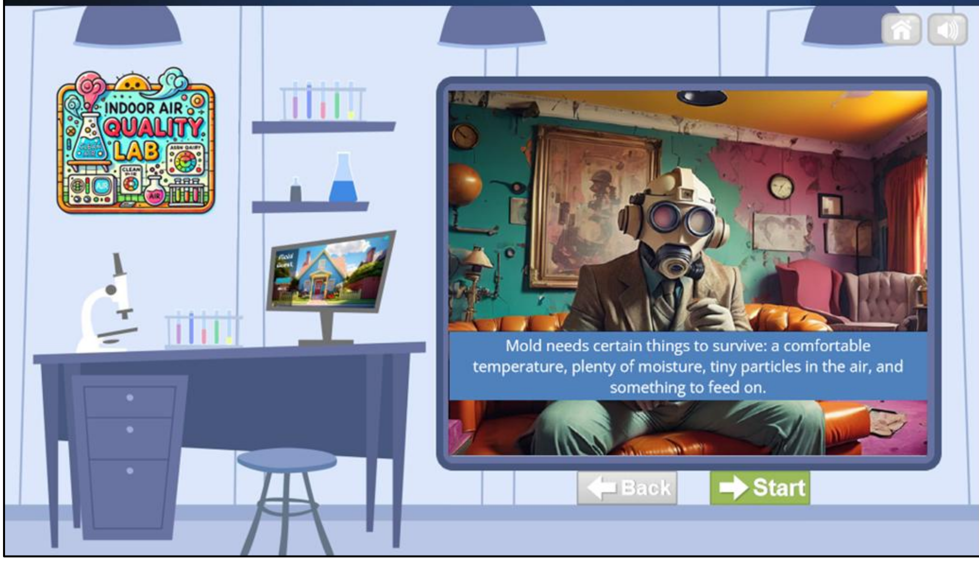

Game modules (M2)

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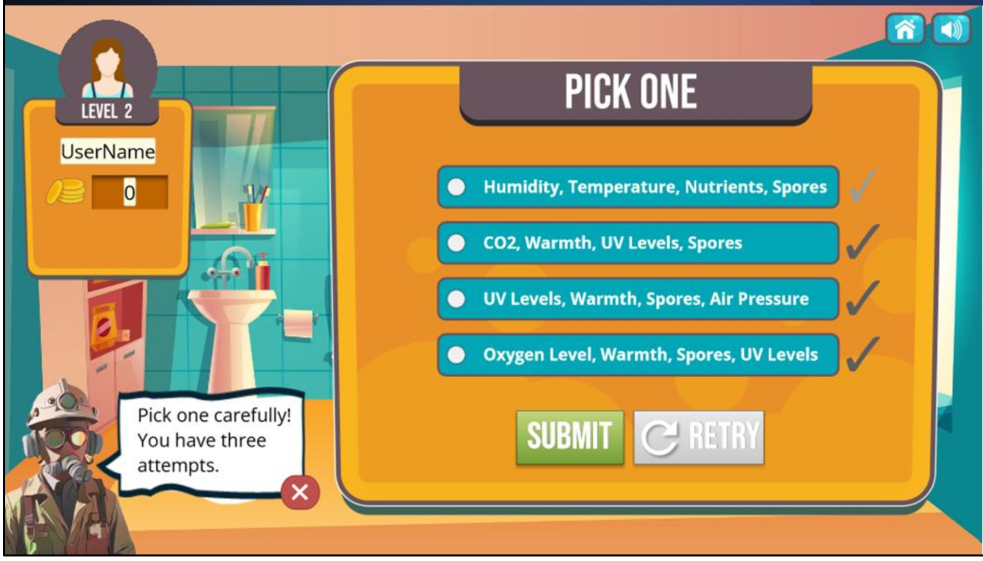

Correct answer:

- Humidity
- Temperature
- Nutrients
- Spores

Game modules (M2)

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Questions:

- Are the options provided clear and relevant to the context of mold formation?
- Is there any additional information that you think users should be tested on in this level?

Game modules (M3)

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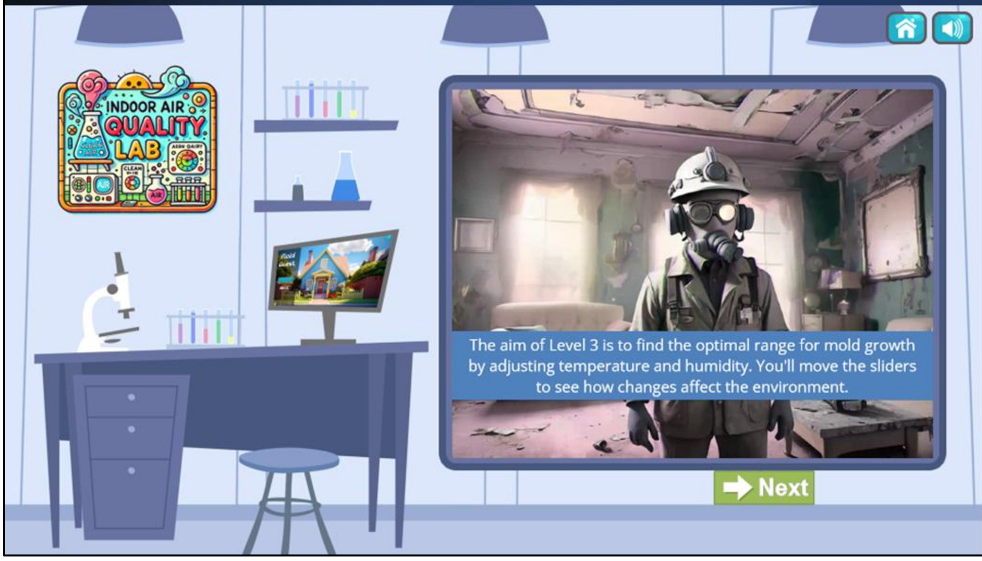

Game modules (M3)

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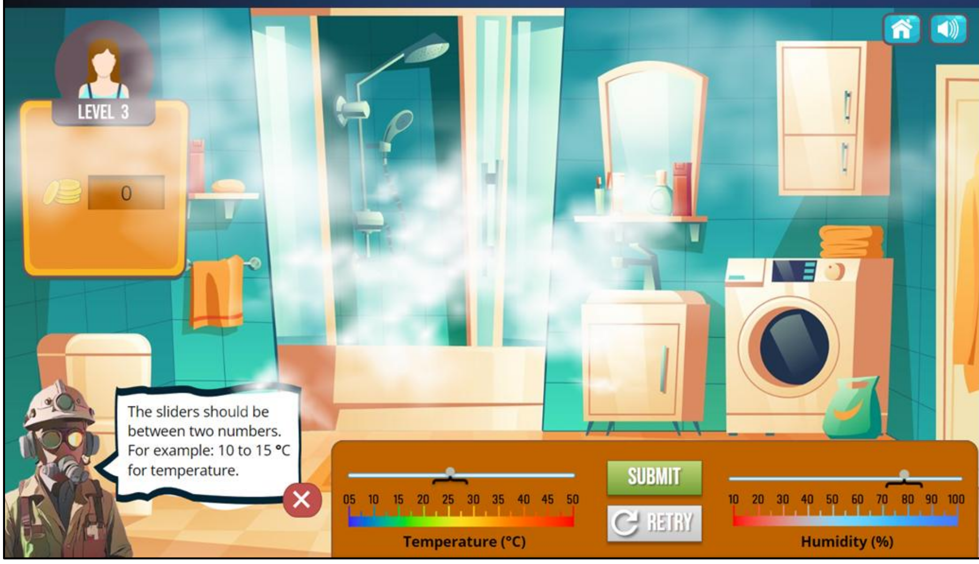


Temperature:
18-22 °C

Humidity:
35-55 %

Game modules (M3)

Questions:

- Are the ranges and values for temperature and humidity realistic based on your expertise?
- What improvements could be made to this feature to better communicate how to prevent mold growth in residential buildings?

Game modules (M4)

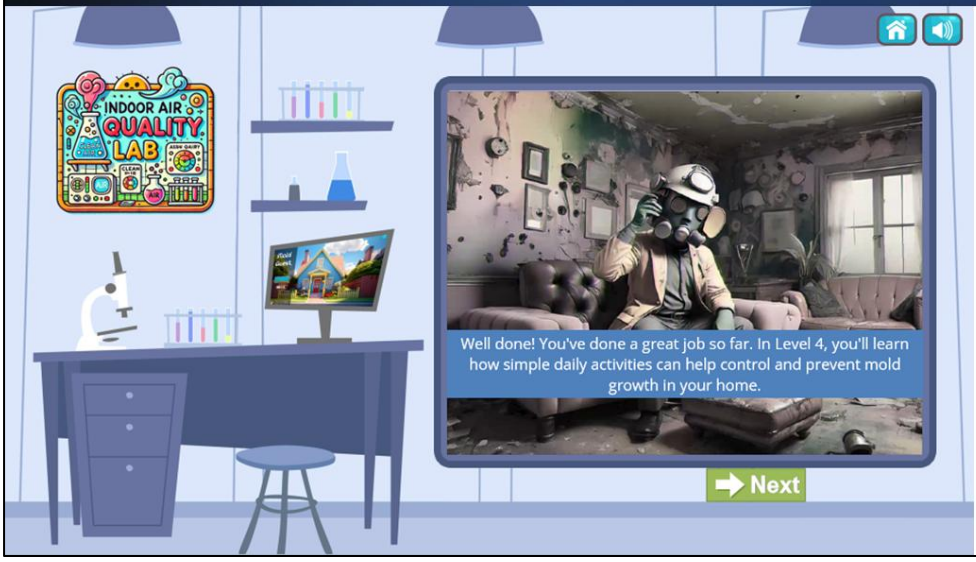
What: Teaching users how daily actions can control and prevent mold growth in residential buildings.

How: Users will apply and evaluate various strategies in the interactive residential environments.

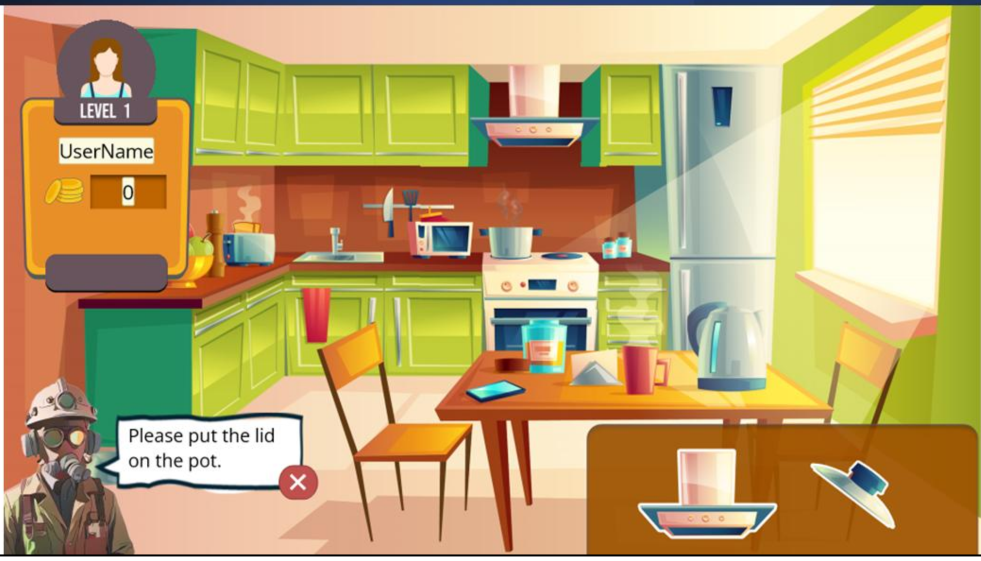
Game modules (M4)

S1: Wipe condensation off windows and walls
S2: Open windows
S3: Avoid using portable gas heaters/ unflued gas heater
S4: Hang washing outside to dry
S5: Use lids on pots when cooking
S6: Use fans and rangehood
S7: Limit sources of moisture such as fish tanks and indoor plants
S8: Use ventilation system
S9: Use dehumidifiers
S10: Vent driers outside
S11: Better heating and insulating the house
S12: Pull beds and furniture away from walls
S13: Leave wardrobes a bit open
S14: Open the curtains during the day

Game modules (M4)



Game modules (M4)



Game modules (M4)

Questions:

- In your opinion, is there any additional strategy that could improve understanding of mold prevention techniques?
- Based on your experience, do you think it is a good idea to simulate bedroom and bathroom for users to apply the strategies?

General Questions

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Questions:

- Based on our discussion today, what do you see as the strengths of *Mold Quest*?
- Is there anything else you would like to add that we haven't covered?

Appendix E: Pre-test Part A: Demographic Information

1. What is your age?

2. What is your gender?

- ○ Male
- ○ Female
- ○ Non-binary/Third gender
- ○ Prefer not to say

3. What type of house are you currently living in?

 **Apartment/Flat**	 **Standalone house**	 **Townhouse**

Other:

4. How often do you play video games (on desktops, laptops, tablets, smartphones, or consoles)?

- ○ Never
- ○ A few times a year
- ○ A few times a month
- ○ A few times a week
- ○ Everyday

Part B and C: Pre-test, Post-test, and Retention

Knowledge Questionnaire

This is a common mold picture that can occur in homes

1. Which areas in a bedroom are most likely to develop mold? List the specific spots where you believe mold is likely to develop in a bedroom (e.g., bed). You may list more than one spot.

2. Which areas in a bathroom are most likely to develop mold? List the specific spots where you believe mold is likely to develop in a bathroom (e.g., mirror). You may list more than one spot.

3. Which conditions are necessary for mold growth?

4. What temperature range (in °C) is most likely to support mold growth? From___ °C to ___ °C

5. What humidity range (in %) is most likely to support mold growth? From___ % to ___ %

6. What strategies can you use to prevent mold growth in your home? List the methods you think can work. You may list more than one method.

NASA Task Load Index (TLX)

Think about the learning experience you went through and answer the questions below that assess how you felt during the learning.

How mentally demanding was the learning?

Very Low Very High

How physically demanding was the learning?

Very Low Very High

How hurried or rushed was the pace of the learning?

Very Low Very High

How successful were you in accomplishing what you were asked to do during the learning?

Very Low Very High

How hard did you have to work during the learning to accomplish your level of performance?

Very Low Very High

How insecure, discouraged, irritated, stressed, and annoyed were you during the learning?

Very Low Very High

NASA Modified System Usability Scale (NMSUS)

Think about the learning experience you went through and answer the questions below that assess the learning tool (game or video) you used.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
I thought the learning tool was easy to use.							
I think I would not need technical support to be able to use the learning tool.							
I found the various functions in this learning tool were well integrated.							
I found the learning tool to be consistent.							
I believe that most people would learn to use this learning tool very quickly.							
I found the learning tool was not difficult to use.							
I felt very confident using the learning tool.							
I do not need a lot of training on this learning tool in order to get going.							

Intrinsic Motivation Inventory (IMI)

Think about the learning experience you went through and answer the questions below that assess how you felt during the learning.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
While I was learning this material, I was thinking about how much I enjoyed it.							
I did not feel nervous at all while learning.							
This material held my attention throughout.							
I will answer this questionnaire seriously so in this question I will choose DISAGREE for this statement.							
I think I understood this material pretty well.							
I would describe this material as very interesting.							
I think I understood this material very well, compared to other people.							
I enjoyed learning this material very much.							
I felt relaxed while learning this material.							
This material was fun to learn.							

General Self-Efficacy Scale (GSE)

Think about the learning experience you went through and answer the questions below that assess your confidence in your ability to handle challenges and achieve learning goals.

	Completely False	**Mostly False**	**Somewhat False**	**Neutral**	**Somewhat True**	**Mostly True**	**Completely True**
I can always manage to come up with a mold prevention strategy for my home.							
I am confident that I can efficiently prevent mold from growing in my home.							
I know how to prevent mold from growing in my home.							
When I am confronted with a mold-growing issue in my home, I can usually find several solutions.							
I can usually prevent mold from growing in my home.							

Behavioral Change Questionnaire

Think about the learning experience you went through and answer the questions below that assess how it has influenced your behaviors and daily practices.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
I regularly check for signs of mold in my home (e.g., in the bathroom or bedroom).							
I have implemented strategies I learned to prevent mold growth in my home.							
Since the learning experience, I have noticed positive changes in my behavior regarding mold prevention at home.							
I regularly apply the knowledge I gained about mold prevention in my daily routine.							
I have taken specific actions at home based on what I learned.							

References

1News. (2023). *Tips and tricks for a mould free home this winter*. Retrieved 5th of April from https://www.1news.co.nz/2023/07/04/tips-and-tricks-for-a-mould-free-home-this-winter/

Abt, C. C. (1987). *Serious games*. University press of America.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179-211. https://doi.org/https://doi.org/10.1016/0749-5978(91)90020-T

Akimoto, H. (2003). Global Air Quality and Pollution. *Science*, *302*(5651), 1716-1719. https://doi.org/doi:10.1126/science.1092666

Al-Rayes, S., Al Yaqoub, F. A., Alfayez, A., Alsalman, D., Alanezi, F., Alyousef, S., AlNujaidi, H., Al-Saif, A. K., Attar, R., Aljabri, D., Al-Mubarak, S. a., Al-Juwair, M. M., Alrawiai, S., Saraireh, L., Saadah, A., Al-umran, A., & Alanzi, T. M. (2022). Gaming elements, applications, and challenges of gamification in healthcare. *Informatics in Medicine Unlocked*, *31*, 100974. https://doi.org/https://doi.org/10.1016/j.imu.2022.100974

Alarcon, D. A. U., Talavera-Mendoza, F., & Paucar, F. H. R. (2025). Evaluation of the Serious Game ABCCI: Usability and Gamification in Teacher Training for Science Education and Environmental Sustainability. *IEEE Access*, *13*, 90601-90611. https://doi.org/10.1109/ACCESS.2025.3569258

All, A., Nuñez Castellar, E. P., & Van Looy, J. (2016). Assessing the effectiveness of digital game-based learning: Best practices. *Computers & Education*, *92-93*, 90-103. https://doi.org/https://doi.org/10.1016/j.compedu.2015.10.007

All, A., Plovie, B., Nunez Castellar, E., & Looy, J. (2017). Pre-test influences on the effectiveness of digital-game based learning: A case study of a fire safety game. *Computers & Education*, *114*. https://doi.org/10.1016/j.compedu.2017.05.018

Allergy New Zealand. (2022). *Mould*. Allergy New Zealand. Retrieved 5th of April from https://www.allergy.org.nz/conditions/environmental-allergies/mould/

Almeida, C., Kalinowski, M., Uchôa, A., & Feijó, B. (2023). Negative effects of gamification in education software: Systematic mapping and practitioner perceptions. *Information and Software Technology*, *156*, 107142.

Alonso-Fernandez, C., Martinez-Ortiz, I., Caballero, R., Freire, M., & Fernández-Manjón, B. (2019). Predicting students' knowledge after playing a serious game based on learning analytics data: A case study. *Journal of Computer Assisted Learning*, *36*, 350-358. https://doi.org/10.1111/jcal.12405

Alsawaier, R. S. (2018). The effect of gamification on motivation and engagement. *The International Journal of Information and Learning Technology*, *35*(1), 56-79. https://doi.org/10.1108/IJILT-02-2017-0009

An, C., & Yamamoto, N. (2016). Fungal compositions and diversities on indoor surfaces with visible mold growths in residential buildings in the Seoul Capital Area of South Korea. *Indoor Air*, *26*(5), 714-723. https://doi.org/https://doi.org/10.1111/ina.12261

Andersen, E., O'Rourke, E., Liu, Y.-E., Snider, R., Lowdermilk, J., Truong, D., Cooper, S., & Popovic, Z. (2012). *The impact of tutorials on games of varying complexity* Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA. https://doi.org/10.1145/2207676.2207687

Anthony, J. (2020). *28,000 New Zealand homes always damp and mouldy: Housing report*. Stuff. Retrieved 12th of April from https://www.stuff.co.nz/business/property/123623884/28000-new-zealand-homes-always-damp-and-mouldy-housing-report

Arcury, T. (1990). Environmental attitude and environmental knowledge. *Human organization*, *49*(4), 300-304.

Arnab, S., Lim, T., Carvalho, M. B., Bellotti, F., de Freitas, S., Louchart, S., Suttie, N., Berta, R., & De Gloria, A. (2015). Mapping learning and game mechanics for serious games analysis. *British Journal of Educational Technology*, *46*(2), 391-411. https://doi.org/https://doi.org/10.1111/bjet.12113

Arumala, J. O. (2006). Mold and the Construction Industry. *International Journal of Construction Education and Research*, *2*(2), 75-89. https://doi.org/10.1080/15578770600775868

Aslam, R., Sharif, F., Baqar, M., Nizami, A.-S., & Ashraf, U. (2023). Role of ambient air pollution in asthma spread among various population groups of Lahore City: a case study. *Environmental Science and Pollution Research*, *30*(4), 8682-8697. https://doi.org/10.1007/s11356-022-19086-1

Auerbach, I. L., & Flieger, K. (1967). The importance of public education in air pollution control. *J Air Pollut Control Assoc*, *17*(2), 102-104. https://doi.org/10.1080/00022470.1967.10468947

Aviv-Reuven, S., & Rosenfeld, A. (2021). Publication patterns' changes due to the COVID-19 pandemic: a longitudinal and short-term scientometric analysis. *Scientometrics*, *126*(8), 6761-6784. https://doi.org/10.1007/s11192-021-04059-x

Baah, C., Govender, I., & Rontala Subramaniam, P. (2024). Enhancing Learning Engagement: A Study on Gamification’s Influence on Motivation and Cognitive Load. *Education Sciences*, *14*, 1115. https://doi.org/10.3390/educsci14101115

Bada, S. O., & Olusegun, S. (2015). Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education*, *5*(6), 66-70.

Baghaei Daemei, A., Feng, Z., & Paes, D. (2025). Developing a serious game for indoor air quality and mold prevention education in residential buildings. *Smart and Sustainable Built Environment*, 1-36. https://doi.org/10.1108/sasbe-07-2025-0374

Baghaei Daemei, A., Lovreglio, R., Feng, Z., Paes, D., & Miller, C. (2025). Gamification for air quality education: A systematic literature review. *Building and Environment*, *270*, 112526. https://doi.org/https://doi.org/10.1016/j.buildenv.2025.112526

Baghaei Daemei, A., Lovreglio, R., Feng, Z., Paes, D., & Miller, C. (2025). Gamification for air quality education: a systematic literature review. *Building and Environment*, 112526. https://doi.org/https://doi.org/10.1016/j.buildenv.2025.112526

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American psychologist*, *37*(2), 122.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Prentice-Hall, Inc.

Bandura, A. (2014). Exercise of personal agency through the self-efficacy mechanism. In *Self-efficacy* (pp. 3-38). Taylor & Francis.

Barbosa, A., Iría, J., Cassola, F., Coelho, A., Portela, J., Ü, K., Madureira, A. G., Zehir, M. A., Özdemir, A., & Soares, F. J. (2017, 30 Nov.-2 Dec. 2017). GReSBAS project: A gamified approach to promote more energy efficient behaviours in buildings. 2017 10th International Conference on Electrical and Electronics Engineering (ELECO),

Barna, B., & Fodor, S. (2018). An Empirical Study on the Use of Gamification on IT Courses at Higher Education. In (pp. 684-692). https://doi.org/10.1007/978-3-319-73210-7_80

Behl, A., Jayawardena, N., Bhardwaj, S., Pereira, V., del Giudice, M., & Zhang, J. (2024). Examining the failure of gamification in implementing innovation from the perspective of problematization in the retail sectors of emerging economies. *Technovation*, *129*, 102902. https://doi.org/https://doi.org/10.1016/j.technovation.2023.102902

Bernstein, J. A., Alexis, N., Bacchus, H., Bernstein, I. L., Fritz, P., Horner, E., Li, N., Mason, S., Nel, A., Oullette, J., Reijula, K., Reponen, T., Seltzer, J., Smith, A., & Tarlo, S. M. (2008). The health effects of nonindustrial indoor air pollution. *Journal of Allergy and*

Clinical Immunology, *121*(3), 585-591. https://doi.org/https://doi.org/10.1016/j.jaci.2007.10.045

Blaak, H., Lkoul, A., Iziki, H., Arechkik, A., Sbai Idrissi, K., El Hilali, S., Razine, R., Belyamani, L., Kharabch, A., & Obtel, M. (2025). Effectiveness of Simulation with a Standardized Patient on Knowledge Acquisition, Knowledge Retention, and Self-Efficacy Among Moroccan Nursing Students: A Quasi-Experimental Study. *Healthcare (Basel)*, *13*(3). https://doi.org/10.3390/healthcare13030318

Blanco, M. N., Shaffer, R. M., Li, G., Adar, S. D., Carone, M., Szpiro, A. A., Kaufman, J. D., Larson, T. V., Hajat, A., Larson, E. B., Crane, P. K., & Sheppard, L. (2024). Traffic-related air pollution and dementia incidence in the Adult Changes in Thought Study. *Environment International*, *183*, 108418. https://doi.org/https://doi.org/10.1016/j.envint.2024.108418

Bosello, M., Delnevo, G., & Mirri, S. (2020). On exploiting Gamification for the Crowdsensing of Air Pollution: A Case Study on a Bicycle-based System. ACM International Conference Proceeding Series,

Boso, À., Álvarez, B., Oltra, C., Garrido, J., Muñoz, C., & Hofflinger, Á. (2020). Out of sight, out of mind: participatory sensing for monitoring indoor air quality. *Environmental Monitoring and Assessment*, *192*(2), 104. https://doi.org/10.1007/s10661-019-8058-z

Brambilla, A., Candido, C., & Gocer, O. (2022). Indoor air quality and early detection of mould growth in residential buildings: a case study. *UCL Open Environ*, *4*, e049. https://doi.org/10.14324/111.444/ucloe.000049

BRANZ. (2015). *Mould and damp*. BRANZ. Retrieved Auguest 15 from https://www.branz.co.nz/healthy-homes-research/hcs/2015-results/mould-and-damp/

BRANZ. (2019a). Indoor air quality in New Zealand homes and garages. *BRANZ Research Now: Indoor air quality #4*. https://doi.org/https://www.branz.co.nz/pubs/research-now/iaq/4-homes-and-garages/

BRANZ. (2019b). An overview of indoor air contaminants in New Zealand houses. *BRANZ Research Now: Indoor air quality #1*, 1-4. https://doi.org/https://www.branz.co.nz/pubs/research-now/iaq/1-overview-contaminants/

Breuer, J., & Bente, G. (2010). Why so serious? On the relation of serious games and learning. *Journal for computer game culture*, *4*, 7-24.

Brod, G. (2021). Toward an understanding of when prior knowledge helps or hinders learning. *npj Science of Learning*, *6*(1), 24. https://doi.org/10.1038/s41539-021-00103-w

Brown, E., & Cairns, P. (2004). *A grounded investigation of game immersion* CHI '04 Extended Abstracts on Human Factors in Computing Systems, Vienna, Austria. https://doi.org/10.1145/985921.986048

Brunekreef, B., & Holgate, S. T. (2002). Air pollution and health. *The lancet*, *360*(9341), 1233-1242.

Bruno, T., Pedro, M., & Pedro, S. (2020). Game-Like 3D Visualisation of Air Quality Data [article]. *Multimodal Technologies and Interaction*, *4*(54), 54-54. https://doi.org/10.3390/mti4030054

Buckley, P., & Doyle, E. (2016). Gamification and student motivation. *Interactive Learning Environments*, *24*(6), 1162-1175. https://doi.org/10.1080/10494820.2014.964263

Building Performance. (2023). *Controlling moisture and damp*. Ministry of Business, Innovation & Employment Retrieved 5th of April from https://www.building.govt.nz/getting-started/smarter-homes-guides/air-quality-moisture-and-ventilation/controlling-moisture-and-damp/

Buonomano, A., Forzano, C., Giuzio, G. F., & Palombo, A. (2023). New ventilation design criteria for energy sustainability and indoor air quality in a post Covid-19 scenario.

Renewable and Sustainable Energy Reviews, *182*, 113378. https://doi.org/https://doi.org/10.1016/j.rser.2023.113378
Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., Pope, C. A., Apte, J. S., Brauer, M., Cohen, A., & et al. (2018). Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *Proceedings of the National Academy of Sciences*, *115*(38), 9592-9597. https://doi.org/doi:10.1073/pnas.1803222115
Byrne, B. M. (2016). *Structural Equation Modeling With AMOS: Basic Concepts, Applications, and Programming*. Routledge. https://doi.org/https://doi.org/10.4324/9781315757421
Cai, Z., Zhang, X., Liu, C., & Zhan, J. (2025). Effects of Digital Game-Based Learning on Student's Problem-Solving Ability: A Three-Level Meta-Analysis. *Journal of Computer Assisted Learning*, *41*(2), e70002. https://doi.org/https://doi.org/10.1111/jcal.70002
Campana, F. E., & Dominguez, F. X. (2021). *Proposal of a Particulate Matter Measurement Device and an Augmented Reality Visualization App as an Educational Tool* Proceedings of the 12th International Conference on Education Technology and Computers, London, United Kingdom. https://doi.org/10.1145/3436756.3437012
Campana, F. E., & Xavier Dominguez, F. (2020, 2020). Proposal of a Particulate Matter Measurement Device and an Augmented Reality Visualization App as an Educational Tool.
Cao, S., & Liu, F. (2022). Learning to play: understanding in-game tutorials with a pilot study on implicit tutorials. *Heliyon*, *8*(11), e11482. https://doi.org/10.1016/j.heliyon.2022.e11482
Carducci, A., Casini, B., Donzelli, G., Verani, M., Bruni, B., Ceretti, E., Zani, C., Carraro, E., Bonetta, S., Bagordo, F., Grassi, T., Villarini, M., Bonizzoni, S., Zagni, L., & Gelatti, U. (2016). Improving awareness of health hazards associated with air pollution in primary school children: Design and test of didactic tools [Article]. *Applied Environmental Education and Communication*, *15*(3), 247-260. https://doi.org/10.1080/1533015X.2016.1181017
Cavalcanti, J., Valls, V., Contero, M., & Fonseca, D. (2021). Gamification and hazard communication in virtual reality: a qualitative study. *Sensors*, *21*(14), 4663.
Chang, C.-C., Liang, C., Chou, P.-N., & Lin, G.-Y. (2017). Is game-based learning better in flow experience and various types of cognitive load than non-game-based learning? Perspective from multimedia and media richness. *Computers in Human Behavior*, *71*, 218-227.
Chatterjee, A., Strong, G., Meinert, E., Milne-Ives, M., Halkes, M., & Wyatt-Haines, E. (2021). The use of video for patient information and education: A scoping review of the variability and effectiveness of interventions. *Patient Education and Counseling*, *104*(9), 2189-2199. https://doi.org/https://doi.org/10.1016/j.pec.2021.02.009
Checa, D., & Bustillo, A. (2020). A review of immersive virtual reality serious games to enhance learning and training. *Multimedia Tools and Applications*, *79*(9), 5501-5527.
Chen, C.-M., Ming-Chaun, L., & Kuo, C.-P. (2023). A game-based learning system based on octalysis gamification framework to promote employees' Japanese learning. *Computers & Education*, *205*, 104899. https://doi.org/https://doi.org/10.1016/j.compedu.2023.104899
Chen, C.-W. (2025). Low-tech serious games in higher education: bridging the digital divide and enhancing student thinking and performance. *Humanities and Social Sciences Communications*, *12*(1), 111. https://doi.org/10.1057/s41599-024-04341-2
Chen, J., He, M., Chen, J., & Zhang, C. (2024). Exploring the role and mechanisms of environmental serious games in promoting pro-environmental decision-making: a focused literature review and future research agenda [Review]. *Frontiers in Psychology*, *Volume 15 - 2024*. https://doi.org/10.3389/fpsyg.2024.1455005

Chen, J., He, M., & She, S. (2025). The impact of environmental serious game on pro-environmental behavior through environmental psychological ownership and environmental self-efficacy. *Scientific Reports*, *15*(1), 27616. https://doi.org/10.1038/s41598-025-11297-z

Cheng, H., Norbäck, D., Zhang, H., Yang, L., Li, B., Zhang, Y., Zhao, Z., Deng, Q., Huang, C., Yang, X., Lu, C., Qian, H., Wang, T., Zhang, L., Yu, W., Wang, J., & Zhang, X. (2024). Home environment exposure and sick building syndrome (SBS) symptoms among adults in southern China: Health associations in 2010 and 2019. *Building and Environment*, *248*, 111061. https://doi.org/https://doi.org/10.1016/j.buildenv.2023.111061

Chittaro, L., & Buttussi, F. (2015). Assessing Knowledge Retention of an Immersive Serious Game vs. a Traditional Education Method in Aviation Safety. *IEEE Transactions on Visualization and Computer Graphics*, *21*(4), 529-538. https://doi.org/10.1109/TVCG.2015.2391853

Choi, J., Mogami, T., & Medalia, A. (2010). Intrinsic motivation inventory: an adapted measure for schizophrenia research. *Schizophr Bull*, *36*(5), 966-976. https://doi.org/10.1093/schbul/sbp030

Chou, Y.-k. (2015). *Actionable Gamification: Beyond Points, Badges, and Leaderboards*. Octalysis Media.

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital Games, Design, and Learning:A Systematic Review and Meta-Analysis. *Review of Educational research*, *86*(1), 79-122. https://doi.org/10.3102/0034654315582065

Çoban, M., & Göktaş, Y. (2023). Comparison of the digital game, drills, and traditional education methods in terms of motivation in earthquake education. *E-Learning and Digital Media*, *20*(1), 25-52.

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. routledge.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education*, *59*(2), 661-686. https://doi.org/https://doi.org/10.1016/j.compedu.2012.03.004

Consalvo, M. (2011). Using your friends: Social mechanics in social games. Proceedings of the 6th International Conference on Foundations of Digital Games,

Consumer. (2022). *Ideas for reducing moisture in your home*. Consumer NZ. Retrieved 5th of April from https://www.consumer.org.nz/articles/ideas-reducing-moisture-in-the-home

Consumer. (2023). *Renter's guide - Dealing with mould*. Consumer. Retrieved 12th of April from https://www.consumer.org.nz/articles/renters-guide-dealing-with-mould

Cook, M. P. (2006). Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science education*, *90*(6), 1073-1091.

Creswell, J. W., & Creswell, J. D. (2022). *Research design: Qualitative, quantitative, and mixed* (Sixth ed.). SAGE.

Dankel, S. J., & Loenneke, J. P. (2021). Effect Sizes for Paired Data Should Use the Change Score Variability Rather Than the Pre-test Variability. *J Strength Cond Res*, *35*(6), 1773-1778. https://doi.org/10.1519/jsc.0000000000002946

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319-340. https://doi.org/https://doi.org/10.2307/249008

Dawson, C. (2019). *Introduction to Research Methods: A Practical Guide for Anyone Undertaking a Research Project*. Little, Brown Book Group.

de Boer, H., Donker, A. S., Kostons, D. D. N. M., & van der Werf, G. P. C. (2018). Long-term effects of metacognitive strategy instruction on student academic performance: A meta-

analysis. *Educational Research Review*, *24*, 98-115. https://doi.org/https://doi.org/10.1016/j.edurev.2018.03.002
De Jans, S., Van Geit, K., Cauberghe, V., Hudders, L., & De Veirman, M. (2017). Using games to raise awareness: How to co-design serious mini-games? *Computers & Education*, *110*, 77-87. https://doi.org/https://doi.org/10.1016/j.compedu.2017.03.009
Deci, E. L., Olafsen, A. H., & Ryan, R. M. (2017). Self-determination theory in work organizations: The state of a science. *Annual review of organizational psychology and organizational behavior*, *4*(1), 19-43.
Deci, E. L., & Ryan, R. M. (2012). Self-determination theory. *Handbook of theories of social psychology*, *1*(20), 416-436.
Deci, E. L., & Ryan, R. M. (2013). *Intrinsic motivation and self-determination in human behavior*. Springer Science & Business Media.
Dede, C. (2009). Immersive interfaces for engagement and learning. *Science*, *323*(5910), 66-69.
Delmas, M. A., & Kohli, A. (2020). Can Apps Make Air Pollution Visible? Learning About Health Impacts Through Engagement with Air Quality Information. *Journal of Business Ethics*, *161*(2), 279-302. https://doi.org/10.1007/s10551-019-04215-7
Dewey, J. (2001). *Democracy and Education: An Introduction to the Philosophy of Education*. The Pennsylvania State University.
Dimitriadou, A., Djafarova, N., Turetken, O., Verkuyl, M., & Ferworn, A. (2021). Challenges in serious game design and development: Educators' experiences. *Simulation & Gaming*, *52*(2), 132-152.
Do-Thi, P., & Do, I. (2022). Quantitative Methodology: Applied Modeling by Using AMOS (Step-By-Step). In S. A. Abdul Karim (Ed.), *Intelligent Systems Modeling and Simulation II: Machine Learning, Neural Networks, Efficient Numerical Algorithm and Statistical Methods* (pp. 645-660). Springer International Publishing. https://doi.org/10.1007/978-3-031-04028-3_40
Domgue K, L. I., Paes, D., Feng, Z., Mander, S., Datoussaid, S., Descamps, T., Rahouti, A., & Lovreglio, R. (2025). Video see-through augmented reality fire safety training: A comparison with virtual reality and video training. *Safety Science*, *184*, 106714. https://doi.org/https://doi.org/10.1016/j.ssci.2024.106714
Douglas, B. D., & Brauer, M. (2021). Gamification to prevent climate change: a review of games and apps for sustainability [Review]. *Current Opinion in Psychology*, *42*, 89-94. https://doi.org/https://doi.org/10.1016/j.copsyc.2021.04.008
Du, C., Li, B., & Yu, W. (2021). Indoor mould exposure: Characteristics, influences and corresponding associations with built environment—A review. *Journal of Building Engineering*, *35*, 101983. https://doi.org/https://doi.org/10.1016/j.jobe.2020.101983
Dyson. (2024). *Global Dyson study1 reveals that indoor pollution levels in New Zealand exceeded WHO safe exposure guidelines for 90% of the year*. Retrieved 11 January from https://www.dyson.co.nz/newsroom/connected-purifier-study#:~:text=5%20levels%20in%20New%20Zealand,(8.46ug%2Fm%C2%B3).
Eccles, J. S., & Wigfield, A. (2020). From expectancy-value theory to situated expectancy-value theory: A developmental, social cognitive, and sociocultural perspective on motivation. *Contemporary Educational Psychology*, *61*, 101859. https://doi.org/https://doi.org/10.1016/j.cedpsych.2020.101859
Elsevier. (2022). Available from: https://www.elsevier.com/solutions/scopus/why-choose-scopus#:~:text=Scopus%20helps%3A,bolster%20performance%2C%20rank%2C%20and%20reputation
Elsevier. (2023). *Choosing the Right Research Methodology: A Guide for Researchers*. Elsevier. Retrieved 10th of April from https://scientific-

publishing.webshop.elsevier.com/research-process/choosing-the-right-research-methodology-a-guide-for-researchers/
Environmental Health Indicators. (2020). *Asthma hospitalisations (0-14 years) [Factsheet]* (Wellington: Environmental Health Indicators Programme, Issue. https://www.ehinz.ac.nz/assets/Factsheets/Released_2020/Asthma-hospitalisations-014-years-20012018-Published-May-2020-v6.pdf
Environmental Health Intelligence. (2025). *Household crowding*.
Environmental Health Intelligence New Zealand. (2022). *Asthma Hospitalisations (0-14 years)*. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.ehinz.ac.nz/assets/Factsheets/Released_2022/Asthma-hospitalisations-014-years-updated-Dec-2022.pdf
EPA. (2023). *Why Indoor Air Quality is Important to Schools*. Retrieved 10th of March from https://www.epa.gov/iaq-schools/why-indoor-air-quality-important-schools#:~:text=EPA%20studies%20of%20human%20exposure,times%20%E2%80%94%20higher%20than%20outdoor%20levels.&text=These%20levels%20of%20indoor%20air,percent%20of%20their%20time%20indoors.
Espinosa-Curiel, I. E., Pozas-Bogarin, E. E., Martínez-Miranda, J., & Pérez-Espinosa, H. (2020). Relationship Between Children's Enjoyment, User Experience Satisfaction, and Learning in a Serious Video Game for Nutrition Education: Empirical Pilot Study. *JMIR Serious Games*, *8*(3), e21813. https://doi.org/10.2196/21813
Evans, P., Vansteenkiste, M., Parker, P., Kingsford-Smith, A., & Zhou, S. (2024). Cognitive Load Theory and Its Relationships with Motivation: a Self-Determination Theory Perspective. *Educational Psychology Review*, *36*(1), 7. https://doi.org/10.1007/s10648-023-09841-2
Ewais, S., & Alluhaidan, A. (2015). *Classification of Stress Management mHealth Apps Based on Octalysis Framework*
Falloon, G. (2019). Using simulations to teach young students science concepts: An Experiential Learning theoretical analysis. *Computers & Education*, *135*, 138-159. https://doi.org/https://doi.org/10.1016/j.compedu.2019.03.001
Fan, L., Han, X., Li, L., Liu, H., Ge, T., Wang, X., Wang, Q., Du, H., Su, L., Yao, X., & Wang, X. (2024). Indoor air quality of urban public transportation stations in China: Based on air quality evaluation indexes. *Journal of Environmental Management*, *349*, 119440. https://doi.org/https://doi.org/10.1016/j.jenvman.2023.119440
Feng, Z., González, V. A., Mutch, C., Amor, R., & Cabrera-Guerrero, G. (2021). Instructional mechanisms in immersive virtual reality serious games: Earthquake emergency training for children. *Journal of Computer Assisted Learning*, *37*(2), 542-556. https://doi.org/https://doi.org/10.1111/jcal.12507
Feng, Z., Lovreglio, R., Yiu, T. W., Acosta, D. M., Sun, B., & Li, N. (2023). Immersive virtual reality training for excavation safety and hazard identification. *Smart and Sustainable Built Environment*, *13*(4), 883-907. https://doi.org/10.1108/sasbe-10-2022-0235
Feng, Z., Lovreglio, R., Yiu, T. W., Acosta, D. M., Sun, B., & Li, N. (2024). Immersive virtual reality training for excavation safety and hazard identification. *Smart and Sustainable Built Environment*, *13*(4), 883-907. https://doi.org/10.1108/SASBE-10-2022-0235
Fernandes, J., Brandão, T., Almeida, S. M., & Santana, P. (2023). An Educational Game to Teach Children about Air Quality Using Augmented Reality and Tangible Interaction with Sensors [Article]. *International Journal of Environmental Research and Public Health*, *20*(5), Article 3814. https://doi.org/10.3390/ijerph20053814
Fernandes, J., Brandão, T., Almeida, S. M., & Santana, P. (2023). An Educational Game to Teach Children about Air Quality Using Augmented Reality and Tangible Interaction with Sensors. *International Journal of Environmental Research and Public Health*, *20*(5), 3814. https://www.mdpi.com/1660-4601/20/5/3814

Finn, S., & O'Fallon, L. (2017). The Emergence of Environmental Health Literacy—From Its Roots to Its Future Potential. *Environmental Health Perspectives*, *125*(4), 495-501. https://doi.org/doi:10.1289/ehp.1409337

Fiorella, L., & Mayer, R. E. (2018). What works and doesn't work with instructional video. *Computers in Human Behavior*, *89*, 465-470. https://doi.org/https://doi.org/10.1016/j.chb.2018.07.015

Fogg, B. J., Cueller, G., & Danielson, D. (2007). Motivating, influencing, and persuading users: An introduction to captology. In *The human-computer interaction handbook* (pp. 159-172). CRC press.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410-8415. https://doi.org/doi:10.1073/pnas.1319030111

Gagné, M., & Deci, E. L. (2005). Self-determination theory and work motivation. *Journal of Organizational behavior*, *26*(4), 331-362.

Gajic, D. (2024). Roberto Gronda: Dewey's Philosophy of Science. *Journal for General Philosophy of Science*. https://doi.org/10.1007/s10838-023-09665-2

Galmarini, E., Marciano, L., & Schulz, P. J. (2024). The effectiveness of visual-based interventions on health literacy in health care: a systematic review and meta-analysis. *BMC Health Serv Res*, *24*(1), 718. https://doi.org/10.1186/s12913-024-11138-1

Gentry, S. V., Gauthier, A., L'Estrade Ehrstrom, B., Wortley, D., Lilienthal, A., Tudor Car, L., Dauwels-Okutsu, S., Nikolaou, C. K., Zary, N., Campbell, J., & Car, J. (2019). Serious Gaming and Gamification Education in Health Professions: Systematic Review. *J Med Internet Res*, *21*(3), e12994. https://doi.org/10.2196/12994

Ghai, A., & Tandon, U. (2023). Integrating gamification and instructional design to enhance usability of online learning. *Education and Information Technologies*, *28*(2), 2187-2206. https://doi.org/10.1007/s10639-022-11202-5

Giakalaras, M. (2016). Gamification and Storytelling.

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning*, *29*(3), 207-219. https://doi.org/https://doi.org/10.1111/j.1365-2729.2012.00489.x

González-Martín, J., Kraakman, N. J. R., Pérez, C., Lebrero, R., & Muñoz, R. (2021). A state–of–the-art review on indoor air pollution and strategies for indoor air pollution control. *Chemosphere*, *262*, 128376. https://doi.org/https://doi.org/10.1016/j.chemosphere.2020.128376

Graham, F. (2023). Daily briefing: We need a proper science of indoor air pollution. *Nature Briefing*. https://doi.org/https://doi.org/10.1038/d41586-023-00415-4

Granić, A., & Marangunić, N. (2019). Technology acceptance model in educational context: A systematic literature review. *British Journal of Educational Technology*, *50*(5), 2572-2593. https://doi.org/https://doi.org/10.1111/bjet.12864

Grossman, B., Conner, S., Mosnaim, G., Albers, J., Leigh, J., Jones, S., & Kenyon, R. (2017). Application of Human Augmentics: A Persuasive Asthma Inhaler. *Journal of Biomedical Informatics*, *67*, 51-58. https://doi.org/https://doi.org/10.1016/j.jbi.2017.02.003

Gunter, G. A., Kenny, R. F., & Vick, E. H. (2008). Taking educational games seriously: using the RETAIN model to design endogenous fantasy into standalone educational games. *Educational technology research and development*, *56*(5), 511-537. https://doi.org/10.1007/s11423-007-9073-2

Hair, J., Hult, G. T. M., Ringle, C., & Sarstedt, M. (2022). *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*.

Hair, J. F. (2009). Multivariate data analysis.
Hamari, J., Koivisto, J., & Sarsa, H. (2014, 6-9 Jan. 2014). Does Gamification Work? -- A Literature Review of Empirical Studies on Gamification. 2014 47th Hawaii International Conference on System Sciences,
Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in Human Behavior*, *54*, 170-179.
Hao, R., Sun, J., Liu, R., Zhao, H., Yao, Z., Wang, H., & Hao, Z. (2024). Emission characteristics, environmental impact, and health risk assessment of volatile organic compounds (VOCs) during manicure processes. *Science of The Total Environment*, *906*, 167464. https://doi.org/https://doi.org/10.1016/j.scitotenv.2023.167464
Hart, S. G. (2006). NASA-task load index (NASA-TLX); 20 years later. Proceedings of the human factors and ergonomics society annual meeting,
Hasanica, N., Ramic-Catak, A., Mujezinovic, A., Begagic, S., Galijasevic, K., & Oruc, M. (2020). The Effectiveness of Leaflets and Posters as a Health Education Method. *Mater Sociomed*, *32*(2), 135-139. https://doi.org/10.5455/msm.2020.32.135-139
Heseltine, E., & Rosen, J. (2009). WHO guidelines for indoor air quality: dampness and mould.
Hong, Y., Saab, N., & Admiraal, W. (2024). Approaches and game elements used to tailor digital gamification for learning: A systematic literature review. *Computers & Education*, 105000. https://doi.org/https://doi.org/10.1016/j.compedu.2024.105000
Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1-55. https://doi.org/https://doi.org/10.1080/10705519909540118
Hu, L., Zhang, L., Yin, R., Li, Z., Shen, J., Tan, H., Wu, J., & Zhou, W. (2021). NEOGAMES: A Serious Computer Game That Improves Long-Term Knowledge Retention of Neonatal Resuscitation in Undergraduate Medical Students [Original Research]. *Frontiers in Pediatrics*, *Volume 9 - 2021*. https://doi.org/10.3389/fped.2021.645776
Hu, L., Zhang, L., Yin, R., Li, Z., Shen, J., Tan, H., Wu, J., & Zhou, W. (2021). NEOGAMES: A Serious Computer Game That Improves Long-Term Knowledge Retention of Neonatal Resuscitation in Undergraduate Medical Students. *Front Pediatr*, *9*, 645776. https://doi.org/10.3389/fped.2021.645776
Hu, Y. (2008). Motivation, usability and their interrelationships in a self-paced online learning environment.
Huang, B., & Hew, K. (2015). *Do points, badges and leaderboard increase learning and activity: A quasi-experiment on the effects of gamification*.
Hung, C.-M., Huang, I., & Hwang, G.-J. (2014). Effects of digital game-based learning on students' self-efficacy, motivation, anxiety, and achievements in learning mathematics. *Journal of Computers in Education*, *1*, 151-166. https://doi.org/10.1007/s40692-014-0008-8
Hunicke, R., Leblanc, M., & Zubek, R. (2004). MDA: A Formal Approach to Game Design and Game Research. *AAAI Workshop - Technical Report*, *1*.
IEEE. (2023). *IEEE at a Glance*. Avalilable from: https://www.ieee.org/about/at-a-glance.html
Ilbeigi, M., Bairaktarova, D., & Ehsani, R. (2024). A Gamified Method for Construction Engineering Education: Learning through Guided Active Exploration. *Journal of Civil Engineering Education*, *150*(2), 05023011. https://doi.org/doi:10.1061/JCEECD.EIENG-2019
IQAir. (2018). *How does outdoor air pollution affect my indoor air quality?* Retrieved 7 February from https://www.iqair.com/newsroom/how-does-outdoor-air-pollution-affect-my-indoor-air-quality

Iyengar, S. S., & Lepper, M. R. (2000). When choice is demotivating: can one desire too much of a good thing? *J Pers Soc Psychol*, *79*(6), 995-1006. https://doi.org/10.1037//0022-3514.79.6.995

Jääskä, E., Lehtinen, J., Kujala, J., & Kauppila, O. (2022). Game-based learning and students' motivation in project management education. *Project Leadership and Society*, *3*, 100055. https://doi.org/https://doi.org/10.1016/j.plas.2022.100055

Janakiraman, S., Watson, S. L., Watson, W. R., & Newby, T. (2021). Effectiveness of digital games in producing environmentally friendly attitudes and behaviors: A mixed methods study. *Computers & Education*, *160*, 104043. https://doi.org/https://doi.org/10.1016/j.compedu.2020.104043

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. *International Journal of Human-Computer Studies*, *66*(9), 641-661. https://doi.org/https://doi.org/10.1016/j.ijhcs.2008.04.004

Jeno, L. M., Diseth, Å., & Grytnes, J.-A. (2021). Testing the METUX Model in Higher Education: Interface and Task Need–Satisfaction Predict Engagement, Learning, and Well-Being [Original Research]. *Frontiers in Psychology*, *Volume 12 - 2021*. https://doi.org/10.3389/fpsyg.2021.631564

Johnson, D., Deterding, S., Kuhn, K.-A., Staneva, A., Stoyanov, S., & Hides, L. (2016). Gamification for health and wellbeing: A systematic review of the literature. *Internet Interventions*, *6*, 89-106. https://doi.org/https://doi.org/10.1016/j.invent.2016.10.002

Jones, A. P. (1999). Indoor air quality and health. *Atmospheric Environment*, *33*(28), 4535-4564. https://doi.org/https://doi.org/10.1016/S1352-2310(99)00272-1

Kāinga Ora. (2023). *Mould and pest control*. Kāinga Ora Homes and Communities. Retrieved 5 of April from https://kaingaora.govt.nz/en_NZ/tenants-and-communities/our-tenants-health-and-safety/mould-and-pest-control/

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental pollution*, *151*(2), 362-367.

Kankaria, A., Nongkynrih, B., & Gupta, S. K. (2014). Indoor air pollution in India: implications on health and its control. *Indian J Community Med*, *39*(4), 203-207. https://doi.org/10.4103/0970-0218.143019

Karać, J., & Stabauer, M. (2017). Gamification in E-Commerce. In F. F.-H. Nah & C.-H. Tan, *HCI in Business, Government and Organizations. Supporting Business* Cham.

Kaushik, V., & Walsh, C. A. (2019). Pragmatism as a research paradigm and its implications for social work research. *Social Sciences*, *8*(9), 255.

Kay, R. H. (2012). Exploring the use of video podcasts in education: A comprehensive review of the literature. *Computers in Human Behavior*, *28*(3), 820-831. https://doi.org/https://doi.org/10.1016/j.chb.2012.01.011

Kayyali, R., Wells, J., Rahmtullah, N., Tahsin, A., Gafoor, A., Harrap, N., & Nabhani-Gebara, S. (2021). Development and evaluation of a serious game to support learning among pharmacy and nursing students. *Currents in Pharmacy Teaching and Learning*, *13*(8), 998-1009. https://doi.org/https://doi.org/10.1016/j.cptl.2021.06.023

Kazar, G., & Comu, S. (2021). Effectiveness of Serious Games for Safety Training: A Mixed Method Study. *Journal of Construction Engineering and Management*, *147*(8), 04021091. https://doi.org/doi:10.1061/(ASCE)CO.1943-7862.0002119

Keall, M. D., Crane, J., Baker, M. G., Wickens, K., Howden-Chapman, P., & Cunningham, M. (2012). A measure for quantifying the impact of housing quality on respiratory health: a cross-sectional study. *Environ Health*, *11*, 33. https://doi.org/10.1186/1476-069x-11-33

Keller, J. M. (2010). *Motivational Design for Learning and Performance: The ARCS Model Approach*. Springer.

Kelly, F. J., & Fussell, J. C. (2015). Air pollution and public health: emerging hazards and improved understanding of risk. *Environmental Geochemistry and Health*, *37*(4), 631-649. https://doi.org/10.1007/s10653-015-9720-1
Khan, K. S., Kunz, R., Kleijnen, J., & Antes, G. (2003). Five Steps to Conducting a Systematic Review. *Journal of the Royal Society of Medicine*, *96*(3), 118-121. https://doi.org/10.1177/014107680309600304
Kim, B. (2012). Harnessing the power of game dynamics: Why, how to, and how not to gamify the library experience. *College & Research Libraries News*, *73*, 465-469. https://doi.org/10.5860/crln.73.8.8811
Kim, J. H., Moon, N., Heo, S. J., & Kwak, J. M. (2024). Effects of environmental health literacy-based interventions on indoor air quality and urinary concentrations of polycyclic aromatic hydrocarbons, volatile organic compounds, and cotinine: A randomized controlled trial. *Atmospheric Pollution Research*, *15*(1), 101965. https://doi.org/https://doi.org/10.1016/j.apr.2023.101965
Kim, S., Park, Y., & Ackerman, M. K. (2021). Designing an indoor air quality monitoring app for asthma management in children: User-centered design approach [Article]. *JMIR Formative Research*, *5*(9), Article e27447. https://doi.org/10.2196/27447
Kim, S., & Sohanchyk, G. (2022). Exploring Children's Engagement in Monitoring Indoor Air Quality: Longitudinal Study [Article]. *JMIR Formative Research*, *6*(1). https://doi.org/10.2196/32404
Kim, S., Song, K., Lockee, B., & Burton, J. (2018). What is Gamification in Learning and Education? In *Gamification in Learning and Education: Enjoy Learning Like Gaming* (pp. 25-38). Springer International Publishing. https://doi.org/10.1007/978-3-319-47283-6_4
Kim, S., Stanton, K., Park, Y., & Thomas, S. (2022). A Mobile App for Children With Asthma to Monitor Indoor Air Quality (AirBuddy): Development and Usability Study. *JMIR Form Res*, *6*(5), e37118. https://doi.org/10.2196/37118
Kim, S., Stanton, K., Park, Y., & Thomas, S. (2022). A Mobile App for Children With Asthma to Monitor Indoor Air Quality (AirBuddy): Development and Usability Study [Article]. *JMIR Formative Research*, *6*(5), Article e37118. https://doi.org/10.2196/37118
Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., Behar, J. V., Hern, S. C., & Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology*, *11*(3), 231-252. https://doi.org/10.1038/sj.jea.7500165
Kline, R. B. (2016). *Principles and practice of structural equation modeling, 4th ed*. The Guilford Press.
Kline, R. B. (2023). *Principles and practice of structural equation modeling*. Guilford publications.
Kogut, P., Çelikkol, B., Vervaet, G., Schreer, O., Renault, S., Alexopoulos, C., Raes, L., & McAleer, S. (2023). Designing Citizen Science tools towards increased awareness and participatory policy making for air quality: The Case of COMPAIR.
Koivisto, J., & Hamari, J. (2019). The rise of motivational information systems: A review of gamification research. *International Journal of Information Management*, *45*, 191-210. https://doi.org/https://doi.org/10.1016/j.ijinfomgt.2018.10.013
Korsavi, S. S., Montazami, A., & Mumovic, D. (2021). Perceived indoor air quality in naturally ventilated primary schools in the UK: Impact of environmental variables and thermal sensation. *Indoor Air*, *31*(2), 480-501.
Kosch, T., Karolus, J., Zagermann, J., Reiterer, H., Schmidt, A., & Woźniak, P. W. (2023). A survey on measuring cognitive workload in human-computer interaction. *ACM Computing Surveys*, *55*(13s), 1-39.

Kosyakoff, M. (2024). *Fill the progress. How to design the perfect game progress bar?* Retrieved 3rd of June from https://medium.com/@MaxKosyakoff/fill-the-progress-fc0fa99cabac

Kramer, M. (2018). Best practices in systems development lifecycle: An analyses based on the waterfall model. *Review of Business & Finance Studies*, *9*(1), 77-84. https://doi.org/https://ssrn.com/abstract=3131958

Krath, J., Schürmann, L., & von Korflesch, H. F. O. (2021). Revealing the theoretical basis of gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning. *Computers in Human Behavior*, *125*, 106963. https://doi.org/https://doi.org/10.1016/j.chb.2021.106963

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into practice*, *41*(4), 212-218. https://doi.org/https://doi.org/10.1207/s15430421tip4104_2

Laamarti, F., Eid, M., & Saddik, A. E. (2014). An overview of serious games. *International Journal of Computer Games Technology*, *2014*, 11-11. https://doi.org/10.1155/2014/358152

Lai, A. K. H., Noor Azhar, A. M. b., Bustam, A. b., Tiong, X. T., Chan, H. C., Ahmad, R. b., & Chew, K. S. (2020). A comparison between the effectiveness of a gamified approach with the conventional approach in point-of-care ultrasonographic training. *BMC Medical Education*, *20*(1), 263. https://doi.org/10.1186/s12909-020-02173-7

Landers, R. N. (2014). Developing a theory of gamified learning: Linking serious games and gamification of learning. *Simulation & Gaming*, *45*(6), 752-768.

Landers, R. N. (2014). Developing a Theory of Gamified Learning:Linking Serious Games and Gamification of Learning. *Simulation & Gaming*, *45*(6), 752-768. https://doi.org/10.1177/1046878114563660

Lassaad, S., & Yamani, H. (2024). Analysing the Impact of Gamification Techniques on Enhancing Learner Engagement, Motivation, and Knowledge Retention: A Structural Equation Modelling Approach. *Electronic Journal of e-Learning*, *22*, 111-124. https://doi.org/10.34190/ejel.22.9.3563

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, *525*(7569), 367-371. https://doi.org/10.1038/nature15371

Leonardi, C., Cappellotto, A., Caraviello, M., Lepri, B., & Antonelli, F. (2014). *SecondNose: an air quality mobile crowdsensing system* Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational, Helsinki, Finland. https://doi-org.ezproxy.massey.ac.nz/10.1145/2639189.2670273

LEVEL. (2023). *Humidity and condensation*. BRANZ. Retrieved 20 of August from https://www.level.org.nz/passive-design/controlling-indoor-air-quality/humidity-and-condensation/

Lewis, A. C., Jenkins, D., & Whitty, C. J. M. (2023). Hidden harms of indoor air pollution — five steps to expose them. *Nature*(614), 220-223. https://doi.org/https://doi.org/10.1038/d41586-023-00287-8

Lewis, R., Stoney, S., & Wild, M. (1998). Motivation and interface design: maximising learning opportunities. *Journal of Computer Assisted Learning*, *14*(1), 40-50. https://doi.org/https://doi.org/10.1046/j.1365-2729.1998.1410040.x

Li, L., Hew, K. F., & Du, J. (2024). Gamification enhances student intrinsic motivation, perceptions of autonomy and relatedness, but minimal impact on competency: a meta-analysis and systematic review. *Educational technology research and development*, *72*(2), 765-796. https://doi.org/10.1007/s11423-023-10337-7

Li, L., Hew, K. F., & Du, J. (2024). Gamification enhances student intrinsic motivation, perceptions of autonomy and relatedness, but minimal impact on competency: a meta-analysis and systematic review. *Educational Technology Research and Development*. https://doi.org/10.1007/s11423-023-10337-7

Li, P., Koziel, J. A., Paris, R. V., Macedo, N., Zimmerman, J. J., Wrzesinski, D., Sobotka, E., Balderas, M., Walz, W. B., Liu, D., Yedilbayev, B., Ramirez, B. C., & Jenks, W. S. (2024). Indoor air quality improvement with filtration and UV-C on mitigation of particulate matter and airborne bacteria: Monitoring and modeling. *Journal of Environmental Management*, *351*, 119764. https://doi.org/https://doi.org/10.1016/j.jenvman.2023.119764

Li, X., Jin, L., & Kan, H. (2019). Air pollution: a global problem needs local fixes. *Nature*, *570*, 437-439. https://doi.org/https://doi.org/10.1038/d41586-019-01960-7

Li, Y., Guan, D., Tao, S., Wang, X., & He, K. (2018). A review of air pollution impact on subjective well-being: Survey versus visual psychophysics. *Journal of Cleaner Production*, *184*, 959-968. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.02.296

Lindsey, M., Chen, S. R., Ben, R., Manoogian, M., & Spradlin, J. (2021). Defining Environmental Health Literacy. *Int J Environ Res Public Health*, *18*(21). https://doi.org/10.3390/ijerph182111626

Ling, T. Y., Teh, Y. B., Kiat Ting, G. K., Wong, W. Z., & Mahmood, N. H. (2021). *Project Kappa: An augmented-reality based sensor data crowdsourcing platform for environmental monitoring* [Conference paper]. 2021 IEEE International Conference on Sensors and Nanotechnology, SENNANO 2021, https://www.scopus.com/inward/record.uri?eid=2-s2.0-85124035109&doi=10.1109%2fSENNANO51750.2021.9642575&partnerID=40&md5=783bdddf7236c5caa0636fb2ca24d684

Liu, Q., Li, H., Shang, W.-l., & Wang, K. (2022). Spatio-temporal distribution of Chinese cities' air quality and the impact of high-speed rail. *Renewable and Sustainable Energy Reviews*, *170*, 112970. https://doi.org/https://doi.org/10.1016/j.rser.2022.112970

Long, B., Simson, J., Watson, D. G., & Mehr, S. A. (2023). How games can make behavioural science better. *Nature*. https://www.nature.com/articles/d41586-023-00065-6

Lopez-Garrido, G. (2025). *Bandura's Self-Efficacy Theory Of Motivation In Psychology*. https://www.simplypsychology.org/self-efficacy.html?

Lovreglio, R., Duan, X., Rahouti, A., Phipps, R., & Nilsson, D. (2021). Comparing the effectiveness of fire extinguisher virtual reality and video training. *Virtual Reality*, *25*(1), 133-145. https://doi.org/10.1007/s10055-020-00447-5

Lozano, A., Canlas, R., Coronel, K., Canlas, J., Duya, J., Macapagal, R., Dungca, E., & Miranda, J. P. (2023). A Game-Based Learning Application to Help Learners to Practice Mathematical Patterns and Structures. *International Journal of Computing Sciences Research*, *7*, 2212-2226. https://doi.org/10.25147/ijcsr.2017.001.1.156

Lu, S., Feng, Z., Lovreglio, R., Wang, F., & Yuan, X. Comparing the productive failure and directive instruction for declarative safety knowledge training using virtual reality. *Journal of Computer Assisted Learning*, *n/a*(n/a). https://doi.org/https://doi.org/10.1111/jcal.12937

Luszczynska, A., Scholz, U., & Schwarzer, R. (2005). The general self-efficacy scale: multicultural validation studies. *The Journal of psychology*, *139*(5), 439-457.

Ma, N., Aviv, D., Guo, H., & Braham, W. W. (2021). Measuring the right factors: A review of variables and models for thermal comfort and indoor air quality. *Renewable and Sustainable Energy Reviews*, *135*, 110436. https://doi.org/https://doi.org/10.1016/j.rser.2020.110436

MacCallum, R. C., Browne, M. W., & Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. *Psychological Methods*, *1*(2), 130-149. https://doi.org/10.1037/1082-989X.1.2.130

Madani, K., Pierce, T. W., & Mirchi, A. (2017). Serious games on environmental management. *Sustainable Cities and Society*, *29*, 1-11. https://doi.org/https://doi.org/10.1016/j.scs.2016.11.007

Magylaitė, K., Kapočius, K., Butleris, R., & Čeponienė, L. (2022). Towards High Usability in Gamified Systems: A Systematic Review of Key Concepts and Approaches. *Applied Sciences*, *12*(16), 8188. https://www.mdpi.com/2076-3417/12/16/8188

Mahajan, S., Kumar, P., Pinto, J. A., Riccetti, A., Schaaf, K., Camprodon, G., Smári, V., Passani, A., & Forino, G. (2020). A citizen science approach for enhancing public understanding of air pollution. *Sustainable Cities and Society*, *52*, 101800. https://doi.org/https://doi.org/10.1016/j.scs.2019.101800

Maheu-Cadotte, M.-A., Cossette, S., Dubé, V., Fontaine, G., Mailhot, T., Lavoie, P., Cournoyer, A., Balli, F., & Mathieu-Dupuis, G. (2018). Effectiveness of serious games and impact of design elements on engagement and educational outcomes in healthcare professionals and students: a systematic review and meta-analysis protocol. *BMJ Open*, *8*(3), e019871. https://doi.org/10.1136/bmjopen-2017-019871

Mahooti-Brooks, N., Storey, E., Yang, C., Simcox, N. J., Turner, W., & Hodgson, M. (2004). Characterization of Mold and Moisture Indicators in the Home. *Journal of Occupational and Environmental Hygiene*, *1*(12), 826-839. https://doi.org/10.1080/15459620490890332

Makransky, G., & Petersen, G. B. (2019). Investigating the process of learning with desktop virtual reality: A structural equation modeling approach. *Computers & Education*, *134*, 15-30. https://doi.org/https://doi.org/10.1016/j.compedu.2019.02.002

MANA. (n.d.). *Indoor Air vs. Outdoor Air*. Retrieved 7 February from https://mana.md/indoor-air-vs-outdoor-air/

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020a). Environmental and Health Impacts of Air Pollution: A Review [Review]. *Frontiers in Public Health*, *8*. https://doi.org/10.3389/fpubh.2020.00014

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020b). Environmental and Health Impacts of Air Pollution: A Review [Review]. *Frontiers in Public Health*, *Volume 8 - 2020*. https://doi.org/10.3389/fpubh.2020.00014

Marcotte, D. E. (2017). Something in the air? Air quality and children's educational outcomes. *Economics of Education Review*, *56*, 141-151. https://doi.org/https://doi.org/10.1016/j.econedurev.2016.12.003

Martín-Martín, A., Thelwall, M., Orduna-Malea, E., & Delgado López-Cózar, E. (2021). Google Scholar, Microsoft Academic, Scopus, Dimensions, Web of Science, and OpenCitations' COCI: a multidisciplinary comparison of coverage via citations. *Scientometrics*, *126*(1), 871-906. https://doi.org/10.1007/s11192-020-03690-4

Mayer, R. E. (2009). *Multimedia learning, 2nd ed* [doi:10.1017/CBO9780511811678]. Cambridge University Press. https://doi.org/10.1017/CBO9780511811678

Mayer, R. E. (2017). Using multimedia for e-learning. *Journal of Computer Assisted Learning*, *33*(5), 403-423. https://doi.org/https://doi.org/10.1111/jcal.12197

McCarron, A., Semple, S., Braban, C. F., Swanson, V., Gillespie, C., & Price, H. D. (2023). Public engagement with air quality data: using health behaviour change theory to support exposure-minimising behaviours. *Journal of Exposure Science & Environmental Epidemiology*, *33*(3), 321-331. https://doi.org/10.1038/s41370-022-00449-2

McDaniel, R., Fiore, S. M., & Nicholson, D. (2010). Serious storytelling: Narrative considerations for serious games researchers and developers. In *Serious game design and development: Technologies for training and learning* (pp. 13-30). IGI Global.

McFarland, J. (2020). Leveling Up for the Teacher-Practitioner: Design and Implementation of a Gamified Application. *Schools*, *17*(1), 115-135.

Mekler, E. D., Brühlmann, F., Tuch, A. N., & Opwis, K. (2017). Towards understanding the effects of individual gamification elements on intrinsic motivation and performance. *Computers in Human Behavior*, *71*, 525-534. https://doi.org/https://doi.org/10.1016/j.chb.2015.08.048

Mentzelopoulos, M., Economou, D., Doumanis, I., Pedersen, F., Kathrani, P., & Bouki, V. (2015, 13 Jul 2015). *Evaluation of a dynamic role-playing platform for simulations based on Octalysis gamification framework* Prague, Czech Republic

Michael, D. R., & Chen, S. L. (2005). *Serious games: Games that educate, train, and inform*. Muska & Lipman/Premier-Trade.

Mirsoleymani, S. F., Vajargah, K. F., Pushaneh, K., Khosravi, A. A., & Vahidi-Asl, M. (2022). The effect of earthquake preparedness training courses through gamification on the students' knowledge level. *Journal of Positive School Psychology*, 9945-9954.

Moghadam, T. T., Ochoa Morales, C. E., Lopez Zambrano, M. J., Bruton, K., & O'Sullivan, D. T. J. (2023). Energy efficient ventilation and indoor air quality in the context of COVID-19 - A systematic review. *Renewable and Sustainable Energy Reviews*, *182*, 113356. https://doi.org/https://doi.org/10.1016/j.rser.2023.113356

Mohd, N. I., Ali, K. N., Bandi, S., & Ismail, F. (2019). Exploring gamification approach in hazard identification training for Malaysian construction industry. *International Journal of Built Environment $ Sustainability*, *6*(1), 51–57.

Moizer, J., Lean, J., Dell'Aquila, E., Walsh, P., Keary, A., O'Byrne, D., Di Ferdinando, A., Miglino, O., Friedrich, R., Asperges, R., & Sica, L. (2019). An approach to evaluating the user experience of serious games. *Computers & Education*, *136*. https://doi.org/10.1016/j.compedu.2019.04.006

Morawska, L., Allen, J., Bahnfleth, W., Bennett, B., Bluyssen, P. M., Boerstra, A., Buonanno, G., Cao, J., Dancer, S. J., Floto, A., Franchimon, F., Greenhalgh, T., Haworth, C., Hogeling, J., Isaxon, C., Jimenez, J. L., Kennedy, A., Kumar, P., Kurnitski, J.,…Yao, M. (2024). Mandating indoor air quality for public buildings. *Science*, *383*(6690), 1418-1420. https://doi.org/doi:10.1126/science.adl0677

Moreira, A., Mendes, F. d. C., Rama, T., Mota, D., Silva, D., & et al. (2022). AlergiaPT: A Portuguese media campaign to inspire people with allergies to make a positive change in their life. *Porto Biomedical Journal*, *7*(1), e169-e169. https://doi.org/https://doi.org/10.1097/j.pbj.0000000000000169

Moreno-Ger, P., Torrente, J., Hsieh, Y. G., & Lester, W. T. (2012). Usability Testing for Serious Games: Making Informed Design Decisions with User Data. *Advances in Human-Computer Interaction*, *2012*(1), 369637. https://doi.org/https://doi.org/10.1155/2012/369637

Moreno, R., & Mayer, R. (2007). Interactive Multimodal Learning Environments. *Educational Psychology Review*, *19*(3), 309-326. https://doi.org/10.1007/s10648-007-9047-2

Morgado, M., Botelho, J., Machado, V., Mendes, J. J., Adesope, O., & Proença, L. (2024). Full title: Video-based approaches in health education: a systematic review and meta-analysis. *Sci Rep*, *14*(1), 23651. https://doi.org/10.1038/s41598-024-73671-7

Morgan, D. L. (2014). Pragmatism as a paradigm for social research. *Qualitative inquiry*, *20*(8), 1045-1053.

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-Generality and Domain-Specificity in Personal Epistemology Research: Philosophical and Empirical Reflections in the Development of a Theoretical Framework. *Educational Psychology Review*, *18*(1), 3-54. https://doi.org/10.1007/s10648-006-9003-6

Nadeem, M., Oroszlanyova, M., & Farag, W. (2023). Effect of Digital Game-Based Learning on Student Engagement and Motivation. *Computers*, *12*(9), 177. https://www.mdpi.com/2073-431X/12/9/177

Naderi, S., & Moafian, F. (2023). The victory of a non-digital game over a digital one in vocabulary learning. *Computers and Education Open*, *4*, 100135. https://doi.org/https://doi.org/10.1016/j.caeo.2023.100135

Naik, N. (2014). A comparative evaluation of game-based learning: Digital or non-digital games? European Conference on Games Based Learning,

Naraghi-Taghi-Off, R., Horst, R., & Dörner, R. (2020). *Gamification Mechanics for Playful Virtual Reality Authoring*. https://doi.org/10.2312/stag.20201247

NASA. (2023). *Usability, Workload, & Error* (NASA-STD-3001 Technical Brief, Issue. https://www.nasa.gov/wp-content/uploads/2023/12/ochmo-tb-005-usability.pdf

Nature Editorial. (2023). Indoor air pollution kills and science needs to step up. *614*(Editorials). https://www.nature.com/articles/d41586-023-00338-0

Nemeth, L., & Lipowsky, F. (2024). The role of prior knowledge and need for cognition for the effectiveness of interleaved and blocked practice. *European Journal of Psychology of Education*, *39*(2), 907-929. https://doi.org/10.1007/s10212-023-00723-3

Nielsen, J. (1994). *Usability engineering*. Morgan Kaufmann.

Niemeyer, G., Garcia, A., & Naima, R. (2009). Black cloud: Patterns towards da future. MM'09 - Proceedings of the 2009 ACM Multimedia Conference, with Co-located Workshops and Symposiums,

Nitzl, C., Roldan, J. L., & Cepeda, G. (2016). Mediation analysis in partial least squares path modeling: Helping researchers discuss more sophisticated models. *Industrial management & data systems*, *116*(9), 1849-1864.

Northolt, M. D., & Bullerman, L. B. (1982). Prevention of Mold Growth and Toxin Production through Control of Environmental Conditions. *Journal of Food Protection*, *45*(6), 519-526. https://doi.org/https://doi.org/10.4315/0362-028x-45.6.519

Oliveira, W., Hamari, J., Shi, L., Toda, A. M., Rodrigues, L., Palomino, P. T., & Isotani, S. (2023). Tailored gamification in education: A literature review and future agenda. *Education and Information Technologies*, *28*(1), 373-406. https://doi.org/10.1007/s10639-022-11122-4

Onwuegbuzie, A. J., Johnson, R. B., & Collins, K. M. (2009). Call for mixed analysis: A philosophical framework for combining qualitative and quantitative approaches. *International Journal of Multiple Research Approaches*, *3*(2), 114-139. https://doi.org/10.5172/mra.3.2.114

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, *38*(1), 1-4.

Paes, D., Feng, Z., King, M., Khorrami Shad, H., Sasikumar, P., Pujoni, D., & Lovreglio, R. (2024). Optical see-through augmented reality fire safety training for building occupants. *Automation in Construction*, *162*, 105371. https://doi.org/https://doi.org/10.1016/j.autcon.2024.105371

Palincsar, A. S. (2012). Social constructivist perspectives on teaching and learning. *An introduction to Vygotsky*, 290-319.

Pallavicini, F., Pepe, A., & Minissi, M. E. (2019). Gaming in Virtual Reality: What Changes in Terms of Usability, Emotional Response and Sense of Presence Compared to Non-Immersive Video Games? *Simulation & Gaming*, *50*(2), 136-159. https://doi.org/10.1177/1046878119831420

Petty, R. E., & Briñol, P. (2011). The elaboration likelihood model. *Handbook of theories of social psychology*, *1*, 224-245.

Petty, R. E., & Cacioppo, J. T. (1986). In L. Berkowitz (Ed.), *Advances in Experimental Social Psychology* (Vol. 19, pp. 123-205). Academic Press. https://doi.org/https://doi.org/10.1016/S0065-2601(08)60214-2

Picciano, P., Qiu, M., Eastham, S. D., Yuan, M., Reilly, J., & Selin, N. E. (2023). Air quality related equity implications of U.S. decarbonization policy. *Nature Communications*, *14*(1), 5543. https://doi.org/10.1038/s41467-023-41131-x

Pintrich, P. R., & De Groot, E. V. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology*, *82*(1), 33–40. https://doi.org/https://doi.org/10.1037/0022-0663.82.1.33

Plagmann, M. (2019). Mould, occupants and house condition. *Comfortable Indoor Environments*, *Build 169*, 58-59. https://www.buildmagazine.org.nz/assets/PDF/Build-169-58-Comfortable-Indoor-Environments-Mould-Occupation-And-House-Condition.pdf

Plass, J. L., D., H. B., & and Kinzer, C. K. (2015). Foundations of Game-Based Learning. *Educational Psychologist*, *50*(4), 258-283. https://doi.org/10.1080/00461520.2015.1122533

Pokric, B., Krco, S., Drajic, D., Pokric, M., Rajs, V., Mihajlovic, Z., Knezevic, P., & Jovanovic, D. (2015). Augmented reality enabled iot services for environmental monitoring utilising serious gaming concept [Article]. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, *6*(1), 37-55. https://doi.org/10.22667/JOWUA.2015.03.31.037

Polychronidou, E., Lalas, A., Tzovaras, D., & Votis, K. (2019). A systematic distributing sensor system prototype for respiratory diseases. In (pp. 191-196): IEEE.

Porter III, J., Boyer, M., & Robb, A. (2018). *Guidelines on Successfully Porting Non-Immersive Games to Virtual Reality: A Case Study in Minecraft* Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play, Melbourne, Australia. https://doi.org/10.1145/3242671.3242677

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Gorber, S. C., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *5*(1), 56. https://doi.org/10.1186/1479-5868-5-56

Pulimeno, M., Piscitelli, P., Colazzo, S., Colao, A., & Miani, A. (2020). Indoor air quality at school and students' performance: Recommendations of the UNESCO Chair on Health Education and Sustainable Development & the Italian Society of Environmental Medicine (SIMA). *Health Promot Perspect*, *10*(3), 169-174. https://doi.org/10.34172/hpp.2020.29

Qiao, J., Zhang, X., Xiao, F., Li, Y., & Gao, W. (2024). Experimental investigation of mold growth risk among typical residential indoor materials: Case study in coastal city, China. *Energy and Buildings*, *304*, 113885. https://doi.org/https://doi.org/10.1016/j.enbuild.2024.113885

Rabin, S. (2009). *Introduction to Game Development* Charles River Media.

Ramanathan, V., & Feng, Y. (2009). Air pollution, greenhouse gases and climate change: Global and regional perspectives. *Atmospheric Environment*, *43*(1), 37-50. https://doi.org/https://doi.org/10.1016/j.atmosenv.2008.09.063

Raufman, J., Blansky, D., Lounsbury, D. W., Mwangi, E. W., Lan, Q., Olloquequi, J., & Hosgood, H. D., 3rd. (2020). Environmental health literacy and household air pollution-associated symptoms in Kenya: a cross-sectional study. *Environ Health*, *19*(1), 89. https://doi.org/10.1186/s12940-020-00643-5

Raynaud, M., Goutaudier, V., Louis, K., Al-Awadhi, S., Dubourg, Q., Truchot, A., Brousse, R., Saleh, N., Giarraputo, A., Debiais, C., Demir, Z., Certain, A., Tacafred, F., Cortes-Garcia, E., Yanes, S., Dagobert, J., Naser, S., Robin, B., Bailly, É.,…Loupy, A. (2021). Impact of the COVID-19 pandemic on publication dynamics and non-COVID-19 research production. *BMC Medical Research Methodology*, *21*(1), 255. https://doi.org/10.1186/s12874-021-01404-9

Razali, N. M., & Wah, Y. B. (2011). Power comparisons of shapiro-wilk, kolmogorov-smirnov, lilliefors and anderson-darling tests. *Journal of statistical modeling and analytics*, *2*(1), 21-33.

Relvas, T. M. B. (2021). *A Serious Game for Raising Air Pollution Awareness in Children* ProQuest Dissertations Publishing].

Ren, K. K., Mohd, N. I., Ali, K. N., Bandi, S., & Ismail, F. (2022). Design Phase of Gamification Framework for Hazard Identification Training in Construction Industry. *International Journal of Interactive Mobile Technologies*, *16*(2).

Reyhing, Y., & Perren, S. (2021). Self-Efficacy in Early Childhood Education and Care: What Predicts Patterns of Stability and Change in Educator Self-Efficacy? *Frontiers in Education*, *6*, 634275. https://doi.org/10.3389/feduc.2021.634275

Richardson, M., Abraham, C., & Bond, R. (2012). Psychological correlates of university students' academic performance: a systematic review and meta-analysis. *Psychol Bull*, *138*(2), 353-387. https://doi.org/10.1037/a0026838

Ritterfeld, U., Cody, M., & Vorderer, P. (2009). *Serious games: Mechanisms and effects*. Routledge.

Robbins, C., & Morrell, J. (2017). Mold, Housing and Wood. *Western Wood Products Association*. https://doi.org/https://stimsonlumber.com/wp-content/uploads/2018/08/Mold_Housing__Wood.pdf

Rodriguez-Calzada, L., Paredes-Velasco, M., & Urquiza-Fuentes, J. (2024). The educational impact of a comprehensive serious game within the university setting: Improving learning and fostering motivation. *Heliyon*, *10*(16), e35608. https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e35608

Rosseel, Y. (2012). lavaan: An R package for structural equation modeling. *Journal of statistical software*, *48*(1), 1-36.

Rutledge, D. (2024). *New Zealand's indoor pollution levels exceed WHO safety guidelines 91 pct of the year - study*. Retrieved 11 January from https://www.newshub.co.nz/home/lifestyle/2024/01/new-zealand-s-indoor-pollution-levels-exceed-who-safety-guidelines-91-pct-of-the-year-study.html

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary educational psychology*, *61*, 101860.

Ryan, R. M., & Deci, E. L. (2024). Self-determination theory. In *Encyclopedia of quality of life and well-being research* (pp. 6229-6235). Springer.

Sailer, M., Hense, J. U., Mayr, S. K., & Mandl, H. (2017). How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. *Computers in Human Behavior*, *69*, 371-380. https://doi.org/https://doi.org/10.1016/j.chb.2016.12.033

Sailer, M., & Homner, L. (2020). The Gamification of Learning: a Meta-analysis. *Educational Psychology Review*, *32*(1), 77-112. https://doi.org/10.1007/s10648-019-09498-w

Sanalife. (2022). *How Outdoor Air Gets Inside - And Why It Becomes More Dangerous When It Does*. Retrieved 7 February from https://www.sanalifewellness.com/blog/how-outdoor-air-gets-inside-and-why-it-becomes-more-dangerous-when-it-does

Sardi, L., Idri, A., & Fernández-Alemán, J. L. (2017). A systematic review of gamification in e-Health. *Journal of Biomedical Informatics*, *71*, 31-48. https://doi.org/https://doi.org/10.1016/j.jbi.2017.05.011

Satish, U., Mendell, M. J., Shekhar, K., Hotchi, T., Sullivan, D., Streufert, S., & Fisk, W. J. (2012). Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2

Concentrations on Human Decision-Making Performance. *Environmental Health Perspectives*, *120*(12), 1671-1677. https://doi.org/doi:10.1289/ehp.1104789

Saunders, M., Lewis, P., & Thornhill, A. (2023). *Research Methods for Business Students*.

Schiavi, B., Havard, V., Beddiar, K., & Baudry, D. (2022). A VR training scenario editor for operation in construction based on BIM 4D and domain expert authoring. *Smart and Sustainable Built Environment*, *12*(5), 1074-1089. https://doi.org/10.1108/sasbe-06-2022-0125

Schmitz, P. I. M., Habbema, J. D. F., Hermans, J., & Raatgever, J. W. (1983). Comparative performance of four discriminant analysis methods for mixtures of continuous and discrete variables. *Communications in Statistics - Simulation and Computation*, *12*(6), 727–751. https://doi.org/https://doi.org/10.1080/03610918308812355

Schrader, C. (2023). Serious Games and Game-Based Learning. In O. Zawacki-Richter & I. Jung (Eds.), *Handbook of Open, Distance and Digital Education* (pp. 1255-1268). Springer Nature Singapore. https://doi.org/10.1007/978-981-19-2080-6_74

Schunk, D., Pintrich, P., & Meece, J. (2022). Motivation in education: Theory, research, and practice. In: Boston: Pearson.

Scorgie, D., Feng, Z., Paes, D., Parisi, F., Yiu, T. W., & Lovreglio, R. (2024). Virtual reality for safety training: A systematic literature review and meta-analysis. *Safety Science*, *171*, 106372. https://doi.org/https://doi.org/10.1016/j.ssci.2023.106372

Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. *International Journal of Human-Computer Studies*, *74*, 14-31. https://doi.org/https://doi.org/10.1016/j.ijhcs.2014.09.006

Sevcenko, N., Ninaus, M., Wortha, F., Moeller, K., & Gerjets, P. (2021). Measuring Cognitive Load Using In-Game Metrics of a Serious Simulation Game [Original Research]. *Frontiers in Psychology*, *Volume 12 - 2021*. https://doi.org/10.3389/fpsyg.2021.572437

Shabanabegum, S. K., Varun, P. V. S., Sai Mohan Krishna, R., & Mohammed Rasool, S. (2021). Air Quality Measurment App For Children With Asthma [Article]. *Turkish Online Journal of Qualitative Inquiry*, *12*(9), 7111-7119. https://doi.org/https://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=eue&AN=160605033&site=eds-live&scope=site&authtype=sso&custid=s3027306

Sharma, W., Lim, W. M., Kumar, S., Verma, A., & Kumra, R. (2024). Game on! A state-of-the-art overview of doing business with gamification. *Technological Forecasting and Social Change*, *198*, 122988. https://doi.org/https://doi.org/10.1016/j.techfore.2023.122988

Shi, A., Wang, Y., & Ding, N. (2022). The effect of game–based immersive virtual reality learning environment on learning outcomes: designing an intrinsic integrated educational game for pre–class learning. *Interactive Learning Environments*, *30*(4), 721-734.

Silva, R. A., West, J. J., Lamarque, J.-F., Shindell, D. T., Collins, W. J., Faluvegi, G., Folberth, G. A., Horowitz, L. W., Nagashima, T., Naik, V., Rumbold, Steven T., Sudo, K., Takemura, T., Bergmann, D., Cameron-Smith, P., Doherty, R. M., Josse, B., MacKenzie, I. A., Stevenson, David S., & Zeng, G. (2017). Future global mortality from changes in air pollution attributable to climate change. *Nature Climate Change*, *7*(9), 647-651. https://doi.org/10.1038/nclimate3354

Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology*, *64*(2), 489-528. https://doi.org/10.1111/j.1744-6570.2011.01190.x

Small, B. M. (2003). Creating mold-free buildings: a key to avoiding health effects of indoor molds. *Arch Environ Health*, *58*(8), 523-527. https://doi.org/10.3200/aeoh.58.8.523-527

Smith, C., Drinkwater, A., Modlich, M., van der Horst, D., & Doherty, R. (2024). IAQ and environmental health literacy: lived experiences of vulnerable people. *Buildings and Cities*. https://doi.org/10.5334/bc.418

Söbke, H., Arnold, U., & Montag, M. (2020, 2020//). Intrinsic Motivation in Serious Gaming A Case Study. Games and Learning Alliance, Cham.

Stachniewicz, R. (2018). Use of thermography for determining places in danger of the mold growth in residential buildings. *Ekonomia i Srodowisko*, *66*(3). https://doi.org/https://ekonomiaisrodowisko.pl/journal/article/view/145

Stamatiadou, M. E., Vryzas, N., Vrysis, L., & Dimoulas, C. (2023). BeeMate the Game: A hunting treasure serious game for raising awareness and audience engagement in air pollution monitoring. 2023 8th International Conference on Smart and Sustainable Technologies, SpliTech 2023,

StatsNZ. (2020). *Housing in Aotearoa*. https://www.stats.govt.nz/reports/housing-in-aotearoa-2020#:~:text=Dampness%20and%20mould%20are%20common,least%20some%20of%20the%20time.

Steinemann, A., Wargocki, P., & Rismanchi, B. (2017). Ten questions concerning green buildings and indoor air quality. *Building and Environment*, *112*, 351-358. https://doi.org/https://doi.org/10.1016/j.buildenv.2016.11.010

Stokstad, E. (2004). Asthma Linked to Indoor Dampness. *Science*, *304*(5675), 1229-1229. https://doi.org/doi:10.1126/science.304.5675.1229b

Street, K. E. S., Malmberg, L.-E., & Stylianides, G. J. (2022). Changes in students' self-efficacy when learning a new topic in mathematics: a micro-longitudinal study. *Educational Studies in Mathematics*, *111*(3), 515-541. https://doi.org/10.1007/s10649-022-10165-1

Strøm-Tejsen, P., Zukowska, D., Wargocki, P., & Wyon, D. P. (2016). The effects of bedroom air quality on sleep and next-day performance. *Indoor Air*, *26*(5), 679-686. https://doi.org/https://doi.org/10.1111/ina.12254

Su, C.-H. (2015). The effects of students' motivation, cognitive load and learning anxiety in gamification software engineering education: a structural equation modeling study. *Multimedia Tools and Applications*, *75*. https://doi.org/10.1007/s11042-015-2799-7

Su, C.-H. (2016). The effects of students' motivation, cognitive load and learning anxiety in gamification software engineering education: a structural equation modeling study. *Multimedia Tools Appl.*, *75*(16), 10013–10036. https://doi.org/10.1007/s11042-015-2799-7

Susi, T., Johannesson, M., & Backlund, P. (2007). Serious games: An overview.

Sweller, J. (2011). Cognitive load theory. In *Psychology of learning and motivation* (Vol. 55, pp. 37-76). Elsevier.

Szolin, K., Kuss, D. J., Nuyens, F. M., & Griffiths, M. D. (2023). "I am the character, the character is me": A thematic analysis of the user-avatar relationship in videogames. *Computers in Human Behavior*, *143*, 107694. https://doi.org/https://doi.org/10.1016/j.chb.2023.107694

Tagliabue, L. C., Mastrolembo Ventura, S., Teizer, J., & Ciribini, A. L. (2020). A serious game for lean construction education enabled by internet of things. Ludic, Co-design and Tools Supporting Smart Learning Ecosystems and Smart Education: Proceedings of the 5th International Conference on Smart Learning Ecosystems and Regional Development,

Taillandier, F., & Adam, C. (2018). Games ready to use: A serious game for teaching natural risk management. *Simulation & Gaming*, *49*(4), 441-470.

Tan, C. K. W., & Nurul-Asna, H. (2023). Serious games for environmental education. *Integrative Conservation*, *2*(1), 19-42. https://doi.org/https://doi.org/10.1002/inc3.18

Tarhini, A., Masa'deh, R. e., Al-Busaidi, K. A., Mohammed, A. B., & Maqableh, M. (2017). Factors influencing students' adoption of e-learning: a structural equation modeling approach. *Journal of International Education in Business*, *10*(2), 164-182.

Tarng, W., Lin, Y.-S., Lin, C.-P., & Ou, K.-L. (2016). Development of a Lunar-Phase Observation System Based on Augmented Reality and Mobile Learning Technologies. *Mobile Information Systems*, *2016*(1), 8352791. https://doi.org/https://doi.org/10.1155/2016/8352791

Teles, B., Mariano, P., & Santana, P. (2020). Game-Like 3D Visualisation of Air Quality Data. *Multimodal Technologies and Interaction*, *4*(54), 54-54. https://doi.org/https://doi.org/10.3390/mti4030054

Thomson, J., Hass, C., Horn, I., Kleine, E., Mitchell, S., Gary, K., Ahmed, I., Hamel, D., & Amresh, A. (2017, 2017/04/02/4). Aspira: Employing a serious game in an mHealth app to improve asthma outcomes. 2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH),

Tiffin University. (2022). *Research Methodologies: A guide on the different types of research methods, and how to determine which one to use in your own research*. Tiffin University. Retrieved 10th of April from https://library.tiffin.edu/researchmethodologies

Tran, V. V., Park, D., & Lee, Y.-C. (2020). Indoor Air Pollution, Related Human Diseases, and Recent Trends in the Control and Improvement of Indoor Air Quality. *International Journal of Environmental Research and Public Health*, *17*(8), 2927. https://doi.org/https://doi.org/10.3390/ijerph17082927

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, *14*(3), 207-222. https://doi.org/https://doi.org/10.1111/1467-8551.00375

Triantafyllou, S. A., Georgiadis, C., & Sapounidis, T. (2025). Gamification in education and training: A literature review. *International Review of Education*, *71*(3), 483-517. https://doi.org/10.1007/s11159-024-10111-8

Tugtekin, E. B., & Koc, M. (2020). Understanding the relationship between new media literacy, communication skills, and democratic tendency: Model development and testing. *New Media & Society*, *22*(10), 1922-1941. https://doi.org/10.1177/1461444819887705

Turner, M. C., Andersen, Z. J., Baccarelli, A., Diver, W. R., Gapstur, S. M., Pope III, C. A., Prada, D., Samet, J., Thurston, G., & Cohen, A. (2020). Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations. *CA: A Cancer Journal for Clinicians*, *70*(6), 460-479. https://doi.org/https://doi.org/10.3322/caac.21632

Underwood, E. (2017). *Brain pollution: Evidence builds that dirty air causes Alzheimer's, dementia*. Science. Retrieved 29 January from https://www.science.org/content/article/brain-pollution-evidence-builds-dirty-air-causes-alzheimer-s-dementia

Unni, B., Tang, N., Cheng, Y. M., Gan, D., & Aik, J. (2022). Community knowledge, attitude and behaviour towards indoor air quality: A national cross-sectional study in Singapore. *Environmental Science & Policy*, *136*, 348-356. https://www.sciencedirect.com/science/article/pii/S1462901122002064

van Roy, R., & Zaman, B. (2018). Need-supporting gamification in education: An assessment of motivational effects over time. *Computers & Education*, *127*, 283-297. https://doi.org/https://doi.org/10.1016/j.compedu.2018.08.018

Varnavsky, A. (2020). *Research of Urban Residents Involvement in Environmental Processes Using a Mobile Environmental Application* International Conference on Convergent Cognitive Information Technologies, Moscow, Russia.

Villagrasa, S., Fonseca, D., & Durán, J. (2014). *Teaching case: applying gamification techniques and virtual reality for learning building engineering 3D arts* Proceedings of the Second International Conference on Technological Ecosystems for Enhancing Multiculturality, Salamanca, Spain. https://doi.org/10.1145/2669711.2669896

Vlachopoulos, D., & Makri, A. (2017). The effect of games and simulations on higher education: a systematic literature review. *International Journal of Educational Technology in Higher Education*, *14*(1), 22.

Wahlström, T. (2025). Using games in environmental and sustainability education: identifying teaching traditions in a game about carbon dioxide emissions. *Environmental Education Research*, 1-17. https://doi.org/10.1080/13504622.2025.2549437

Waltemate, T., Gall, D., Roth, D., Botsch, M., & Latoschik, M. E. (2018). The Impact of Avatar Personalization and Immersion on Virtual Body Ownership, Presence, and Emotional Response. *IEEE Transactions on Visualization and Computer Graphics*, *24*(4), 1643-1652. https://doi.org/10.1109/TVCG.2018.2794629

Wang, J. (2023). Predictors of Flow Experience and Knowledge Acquisition in a STEM Game. *International Journal of Serious Games*, *10*(3), 67-82. https://doi.org/https://doi.org/10.17083/ijsg.v10i3.619

Wang, J., Hu, X., Yang, T., Jin, J., Hao, J., Kelly, F., Huang, J., & Li, G. (2024). Ambient air pollution and the dynamic transitions of stroke and dementia: a population-based cohort study. *eClinicalMedicine*, *67*, 102368. https://doi.org/10.1016/j.eclinm.2023.102368

Wang, J., Stebbins, A., & Ferdig, R. (2021). Examining the effects of students' self-efficacy and prior knowledge on learning and visual behavior in a physics game. *Computers & Education*, *178*. https://doi.org/10.1016/j.compedu.2021.104405

Wang, Y., Sun, M., Yang, X., & Yuan, X. (2016). Public awareness and willingness to pay for tackling smog pollution in China: a case study. *Journal of Cleaner Production*, *112*, 1627-1634. https://doi.org/https://doi.org/10.1016/j.jclepro.2015.04.135

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., de Souza Dias, B. F., Ezeh, A., Frumkin, H., Gong, P., Head, P., Horton, R., Mace, G. M., Marten, R., Myers, S. S., Nishtar, S., Osofsky, S. A., Pattanayak, S. K., Pongsiri, M. J., Romanelli, C.,…Yach, D. (2015). Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation: Commission on planetary health. *The lancet*, *386*(10007), 1973-2028. https://doi.org/10.1016/S0140-6736(15)60901-1

WHO. (2019). *Health consequences of air pollution on populations*. Retrieved 15 November from https://www.who.int/news/item/15-11-2019-what-are-health-consequences-of-air-pollution-on-populations#:~:text=It%20increases%20the%20risk%20of,poor%20people%20are%20more%20susceptible.

WHO. (2023). *Household air pollution*. Retrieved 7 February from https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

Wilkinson, P. (2016). A brief history of serious games. Entertainment Computing and Serious Games: International GI-Dagstuhl Seminar 15283, Dagstuhl Castle, Germany, July 5-10, 2015, Revised Selected Papers,

Williams, D. M., & Rhodes, R. E. (2016). The confounded self-efficacy construct: conceptual analysis and recommendations for future research. *Health Psychol Rev*, *10*(2), 113-128. https://doi.org/10.1080/17437199.2014.941998

Wohlin, C. (2014). *Guidelines for snowballing in systematic literature studies and a replication in software engineering* Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering, London, England, United Kingdom. https://doi.org/10.1145/2601248.2601268

Wohlin, C., Kalinowski, M., Romero Felizardo, K., & Mendes, E. (2022). Successful combination of database search and snowballing for identification of primary studies in systematic literature studies. *Information and Software Technology*, *147*, 106908. https://doi.org/https://doi.org/10.1016/j.infsof.2022.106908

Wolf, E. J., Harrington, K. M., Clark, S. L., & Miller, M. W. (2013). Sample Size Requirements for Structural Equation Models: An Evaluation of Power, Bias, and Solution Propriety. *Educ Psychol Meas*, *76*(6), 913-934. https://doi.org/10.1177/0013164413495237

Wouters, P., Nimwegen, C., Oostendorp, H., & Spek, E. (2013). A Meta-Analysis of the Cognitive and Motivational Effects of Serious Games. *Journal of Educational Psychology*, *105*, 249. https://doi.org/10.1037/a0031311

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249-265. https://doi.org/10.1037/a0031311

Yates, D. (2021). 3. Why so serious? The role of non-serious games in sparking educational curiosity: a reflection. *Games, Simulations and Playful Learning in Business Education*, 23.

Yen, W.-C., & Lin, H.-H. (2020). Investigating the effect of flow experience on learning performance and entrepreneurial self-efficacy in a business simulation systems context. *Interactive Learning Environments* *30*(9), 1593-1608. https://doi.org/https://doi.org/10.1080/10494820.2020.1734624

Yildirim, I. (2017). The effects of gamification-based teaching practices on student achievement and students' attitudes toward lessons. *The Internet and Higher Education*, *33*, 86-92. https://doi.org/https://doi.org/10.1016/j.iheduc.2017.02.002

Zhang, B., & Robb, N. (2021). A Comparison of the Effects of Augmented Reality N-Back Training and Traditional Two-Dimensional N-Back Training on Working Memory. *SAGE Open*, *11*(2), 21582440211014507. https://doi.org/10.1177/21582440211014507

Zhang, B., Weuve, J., Langa, K. M., D'Souza, J., Szpiro, A., Faul, J., Mendes de Leon, C., Gao, J., Kaufman, J. D., Sheppard, L., Lee, J., Kobayashi, L. C., Hirth, R., & Adar, S. D. (2023). Comparison of Particulate Air Pollution From Different Emission Sources and Incident Dementia in the US. *JAMA Intern Med*, *183*(10), 1080-1089. https://doi.org/10.1001/jamainternmed.2023.3300

Zhang, X., Du, J., & Chow, D. (2023). Association between perceived indoor environmental characteristics and occupants' mental well-being, cognitive performance, productivity, satisfaction in workplaces: A systematic review. *Building and Environment*, *246*, 110985. https://doi.org/https://doi.org/10.1016/j.buildenv.2023.110985

Zichermann, G., & Cunningham, C. (2011). *Gamification by design: Implementing game mechanics in web and mobile apps*. " O'Reilly Media, Inc.".