

# Prototyping a Serious Game to Enhance Indoor Air Quality Awareness Among the General Public in New Zealand

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**Abstract.** Poor indoor air quality (IAQ) is directly linked to respiratory and cardiovascular diseases, allergies, and other health conditions. Mold significantly contributes to poor IAQ, which is closely related to various health issues, including respiratory and cardiovascular conditions. Raising public awareness about IAQ is essential for empowering individuals to adopt preventive measures. This study aims to develop a serious game designed to educate the general public on preventing mold growth in residential buildings in New Zealand. The game, developed using Articulate Storyline 360, engages users in identifying mold-prone areas in kitchens, bedrooms, and bathrooms, understanding mold formation factors, optimal temperature and humidity ranges, and applying effective mitigation strategies. A semi-structured interview involving 12 expert participants was conducted to validate the game's content. Participants highlighted key mold-prone areas, including furniture near exterior walls, ceiling corners, and curtains, and emphasized the importance of managing moisture and cold surfaces to prevent mold growth. They recommended practical strategies such as wiping condensation, using extraction fans, and maintaining indoor humidity levels between 40–60% to mitigate mold risks effectively.

## 1 Introduction

Indoor Air Quality (IAQ) is a critical aspect of environmental health, intimately linked to the broader issue of air pollution [1]. Being exposed to poor IAQ leads to health impacts in both the short and long term, with particularly severe consequences for individuals who are already unwell [2]. The repercussions of poor IAQ extend beyond immediate discomfort, which means it brings about irritation to the nose, throat, eyes, and skin, headaches, dizziness, or nausea [3], emphasizing the urgent need for holistic solutions. Thus, it is critical to educate individuals about the sources and consequences of indoor air pollution, empowering them with knowledge to make informed decisions and change behaviours [4, 5]. According to a factsheet released by Environmental Health Indicators [6], “*In 2018, there were 7,182 asthma-related hospitalizations (including wheezing) among children aged 0–14 years in New Zealand. The number of asthma hospitalizations increased between 2006 and 2018.*” It is also mentioned that various environmental triggers and exposure to household pollutants (e.g., dust mites, animal fur, pollen, and mold) may affect asthma. Also, as per a research report by Consumer [7], “*According to a 2015 BRANZ survey, more than half of New Zealand rental houses had visible mould. In 2018, about 28,000 homes in New Zealand were reported to be constantly damp and always have visible mould over an A4 size [8].*” Therefore, it is evident that addressing mold issues in New Zealand homes is urgent. Educating people about IAQ is of paramount importance due to the direct and

profound impact it has on human health [9]. The air we breathe indoors can be laden with a variety of pollutants, including PM, VOCs, and other harmful substances [10]. One promising avenue for delivering engaging and effective air quality education is through gamification [11, 12]. Gamification applies game elements and principles in non-game contexts [13–15]. Integrating educational content on air quality into interactive and immersive games can enhance people's awareness [16]. This approach utilises the enjoyment and motivational aspects of games to encourage positive changes in behaviour [17, 18].

As such, this study aims to develop a serious game called “Mold Quest” designed to empower the general public to prevent mold growth in New Zealand's residential buildings. This study addresses a gap in existing research on the educational applications of gamification for indoor air quality education. As such, this research seeks to contribute novel insights into how gamification can teach people when and how to improve their indoor environments. Additionally, the study aligns with the United Nations Sustainable Development Goals, focusing on improving health (SDG 3) and promoting sustainable cities (SDG 11).

## 2 Development Workflow

This study employs a multi-phase methodology to develop and validate the educational content for a serious game aimed at teaching mold prevention in residential buildings across New Zealand. The

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methodology integrates literature and experts' feedback to ensure the game content's accuracy, relevance, and educational value.

## 2.1 Literature Review

The first phase involved an extensive review of New Zealand websites, reports, regulations, and academic literature on mold prevention, focusing on mold-prone areas in residential buildings, key mold growth elements, optimal temperature and humidity conditions, and prevention strategies. The collected data helped identify potential mold-prone areas, categorized as correct or incorrect based on existing knowledge and guidelines. This is the foundation of the game's prototype, since this literature review contributed to establishing the learning objectives and content of the game. Full details of the educational content can be found in our previous study [19].

## 2.2 Prototype Development

The game prototype introduces users as new residents in a house, aiming to teach them how to prevent mold growth. It consists of four interactive levels, each designed to deliver essential information in an engaging and accessible manner. Players begin by selecting an avatar and entering their name, which is displayed throughout the game to enhance personalization. The game utilizes a 2D interactive environment to ensure accessibility for users from diverse backgrounds and educational levels. Progression is task-based, requiring users to complete objectives to unlock subsequent scenes or levels (see Fig. 1).



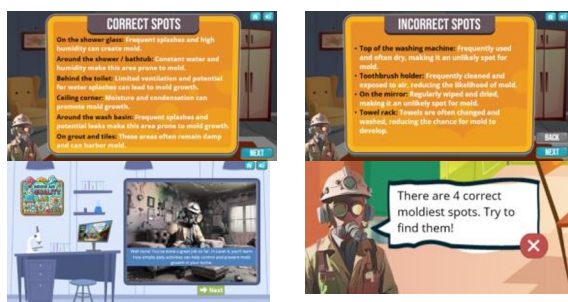
**Figure 1.** The narrative system in the game, and instructional narratives before the game begins, give the players essential information, key features, gameplay instructions, and tips

Level 1 focuses on identifying mold-prone areas in three key rooms: the kitchen, bedroom, and bathroom. Users interact with the environment by selecting highlighted spots classified as correct or incorrect mold-prone locations. Correct choices earn users up to 10 points, while incorrect selections deduct up to 3 points. To support user engagement and guidance, a virtual assistant named Mr. Grumpy Moldwell introduces each level, offering essential knowledge and instructions. Level 2 introduces users to the four key elements for mold growth through multiple-choice questions. Players have three attempts to answer correctly, with a maximum of 10 points awarded for correct answers and a 3-point deduction for incorrect attempts. Level 3 focuses on temperature and humidity, where users interact with two sliders to learn about the optimal ranges for preventing mold growth. Level 4 challenges users to apply the knowledge they've gained by identifying mold prevention strategies within the same three rooms from Level 1. Players can track their cumulative points and progress throughout the game via the status panel. This interactive, step-by-step approach aims to foster a deeper understanding of mold prevention strategies, encouraging evidence-based learning in a practical, engaging format. Figure 2 illustrates the three main rooms (kitchen, bedroom, and bathroom) at the top and Levels 2 to 4 at the bottom, respectively.



**Figure 2.** Some screenshots of the game's primary levels

This scenario-based game is accessible on PCs, laptops, tablets, and smartphones and is designed for independent play. It guides players through tasks without supervision, with integrated instructions and tips ensuring consistent support for all. The game promotes problem-solving skills while educating users on mold prevention in residential homes. The target audience is the general public, especially those living in rental properties, given that mold is common in New Zealand rentals. A status panel in the top-left corner tracks user points and remaining tasks. Upon completing the required tasks, users receive feedback explaining the reasoning behind each correct or incorrect response (Fig. 3).



**Figure 3.** Feedback loop for correct and incorrect answer explanations

The status panel in the top-left corner displays the user’s avatar, name, scores, and progress, adding a personalized touch to the experience. Players can select their avatar and name, with both shown in the status panel (Fig. 4). The cartoonish 2D design helps players unfamiliar with video games navigate the game easily. By using simple language and offering clear instructions and feedback at the beginning and end of each level, the game ensures accessibility for a broad audience. The design choices, such as step-by-step progression and structured learning objectives, aim to create an engaging and educational user experience.



**Figure 4.** Avatar selection and status panel

### 2.3 Expert Interviews

To validate and refine the identified learning outcomes, semi-structured interviews were conducted with experts in the field. The interview questions were designed to gather feedback on the accuracy and contextual relevance of the mold-prone areas identified in the literature. Experts were also asked to provide insights on gamification strategies to enhance the game’s educational impact. The findings from expert interviews were compared with data obtained from the literature and web sources to refine the results. To begin, we identified potential mold-prone areas in the literature, categorizing them as correct or incorrect, and sought feedback from interviewees to evaluate their accuracy within the game context. This comparative approach helped ensure the precision and relevance of the information integrated into the game.

### 2.4 Prototype Improvement

Following data collection, the findings from expert interviews were compared with the literature and web data to refine the identified mold-prone areas. This comparative approach ensured that the information integrated into the game was precise and relevant to real-world scenarios. Feedback from the interviews informed

adjustments to the educational content, helping to align it with evidence-based knowledge and expert opinions. The game was developed using Articulate Storyline 360, a widely used e-learning tool for creating interactive online courses, presentations, and simulations. While Storyline 360 has its scripting language, it also supports JavaScript for advanced interactivity and customization. We adopted the waterfall development approach, known for its structured, sequential design process. This model includes phases such as requirements analysis, design, implementation, testing, and maintenance, with each phase building on the outcomes of the previous one [20, 21]. This approach provided a clear framework for creating an educational game focused on air quality awareness. To ensure evidence-based learning objectives for mold prevention, we reviewed publicly available resources, including New Zealand websites, reports, regulations, and academic literature. We also validated the relevance of these objectives through expert feedback collected via semi-structured interviews, as discussed in the next section.

## 3 Learning Objectives and Educational Content

In this section, we present the learning objectives (LOs) and educational content collected through a literature review and interviews. Each LO is categorized into four game modules to facilitate step-by-step learning for users.

### 3.1 Learning Objectives

The game is designed with four LOs that align with its different levels. The LOs are designed based on Bloom’s Taxonomy [22]. The four LOs are:

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

### 3.2 Educational Content

First, the educational content was developed based on official public sources, including relevant governmental regulations, standards, building codes, and international publications. For LO1, we identified several spots prone to mold growth in three rooms: the kitchen, bedroom, and bathroom. For LO2, we found the key elements for mold to form, including temperature, humidity, spores, and nutrients, across the published literature [23, 24]. The educational content for LO3 encompasses the optimal ranges of temperature and moisture to prevent mold growth. For optimum occupant comfort and health, a humidity of 35-55% [25, 26] and an indoor temperature between 18-22°C is recommended [27-29]. For LO4, we identified 14 strategies from several

official sources. Among those strategies, we will apply the most practical and effective ones within the game. These include wiping condensation off windows and walls and opening windows. It is 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 range hoods 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 [29-33]. See Figure 5 for further details.

email invitations, but only 12 responded, participating in the interviews. The interviewees 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 agreement to participate. The interviews were conducted over approximately one month, beginning on October 17, 2024, and concluding on November 14, 2024.

The participants in the study represented a diverse group across various demographics and professional backgrounds. Age-wise, 9.1% were between 25–34 years, 36.4% were 35–44 years, 27.3% were 45–54 years, and 27.3% fell in the 55–64 age range. The gender distribution included 36.4% female and 63.6% male participants. Regarding educational qualifications, 18.2% held an associate degree, 18.2% had a bachelor's degree, 27.3% had a master's degree, and 36.4% possessed doctoral-level education. Professionally, participants included advisors, building scientists, senior lecturers, sustainability specialists, research scientists, architects, senior technicians, and consultants. Regarding professional experience, 9.1% had 1–5 years, 18.2% had 6–10 years, 27.3% had 11–15 years, and 45.5% had over 16 years of experience in their respective fields.

The interview questions were divided into five parts, covering learning objectives 1 to 4, followed by a final section with general questions. In **Part 1**, participants were asked whether the game accurately represented common mold-prone areas in kitchens, bedrooms, and bathrooms. They were also invited to suggest other rooms that could be included in the game, such as living rooms, and to identify any important spots for mold growth that may have been overlooked. **Part 2** focused on the clarity and relevance of the options provided for mold formation. Participants were asked whether the options were clear and appropriate and whether additional information should be included to enhance user understanding. In **Part 3**, participants evaluated whether the ranges and values for temperature and humidity were realistic based on their expertise. They also suggested improving this feature to better communicate strategies for preventing mold growth in residential buildings. **Part 4** sought input on whether additional strategies could enhance users' understanding of mold prevention techniques. Participants were also asked if simulating the bedroom and bathroom for users to apply these strategies was effective and beneficial based on their experience. Finally, **Part 5** included general questions aimed at identifying the overall strengths of the game based on the discussion. Participants also had the opportunity to share any additional thoughts or insights that may not have been covered in the interview.

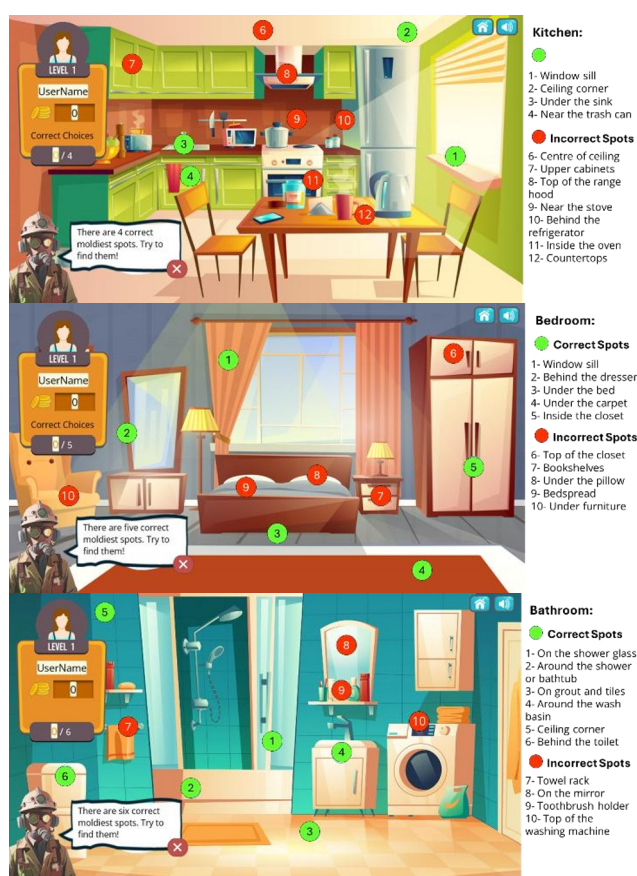


Figure 5. Common mold-prone spots in dwellings

#### 4 Content Validation: Interview

To validate the content of the game gathered from literature, a semi-structured interview was conducted with 12 experts in New Zealand. The communication process began with an online invitation via email, with scheduling facilitated through the Doodle platform ([www.doodle.com](http://www.doodle.com)). This research was approved by the Massey University Human Ethics Low-Risk Notification on 19/08/2024 (approval number 4000028748). The interviews were held on Microsoft Teams, lasting approximately 40 minutes each, depending on the participant's pace. Video recordings and transcriptions were generated using Microsoft Teams. NVivo software was utilized for coding and thematic analysis, which allowed for an examination of the qualitative data. We contacted over 60 experts via

#### 5 Interview Results and Discussion

In the following, we provided insights gathered from expert opinions regarding common mold-prone areas within rooms, the essential elements for mold formation, optimal temperature and humidity ranges, and effective

strategies to mitigate mold growth. Table 1 compares the findings of the literature and web sources with the interview results.

**Table 1.** Common mold-prone spots in dwellings

Rooms	Spots				
	Literature and web sources	Interview			
Kitchen	Correct spots	Windowsill	Windowsill, frame, and glasses (around the windows)		
		Under the sink	Under the sink		
		Ceiling corner	Ceiling corner (if the refrigerator is not nearby underneath)		
		Near the trash can	Not in a short-term period, only in a situation of leaving the trash for a long period		
	Incorrect spots	Under the sink	Only if there is a leakage there		
		Center of ceiling	We witnessed various houses in which the ceilings were mold		
		Behind the fridge	It is not correct since fridges generate heat; they most likely reduce moisture unless they are leaking		
		Upper cabinets	Cupboards, specifically base cabinets, are more likely prone to mold growth		
		Top-of-the-range hood	The top of the range hood is typically not a mold-prone area because it is exposed to airflow and heat from cooking		
		Near the stove	Agreed		
		Inside the oven	Agreed		
	Bedroom	Correct	Countertops	No, because most of the time, we clean them and wipe the dust out	
			Windowsill	Windowsill, frame, glasses (around the windows), and curtains	
Behind the dresser			Definitely. Especially if the dresser is positioned in front of the exterior wall		
Under the bed			Limited airflow under the bed can trap moisture, making it a potential mold-prone area		
Underneath the carpet			It can be prone to mold growth, especially if there is trapped moisture or poor ventilation		
Incorrect		Inside the closet	Closets can be prone to mold due to poor ventilation		
		Top of the closet	Some participants mentioned that the top of a closet is less likely to accumulate the conditions necessary for mold growth. However, others believed that if the inside of the closet is prone to mold growth, the top would be as well.		
		Bedside table	Most likely not a mold-prone area		
		Under the pillow	In a very rare situation		
		Bedsread	In a very rare situation		
		Under furniture	Similar to under the bed unless the furniture's legs are higher off the ground		
		Bathroom	Correct	On the shower glass	Agreed
				Around the shower or bathtub	Agreed
On grout and tiles	Agreed				
Around the wash basin	Usually, there is a mirror in front of it, and we clean it frequently				
Ceiling corner	Definitely, also on the edges and throughout the ceilings				
Behind the toilet	It is not a mold-prone area unless there is a leakage there				
Incorrect	Towel rack		30% of the participants agreed that if the towel rack is wooden		
	On the mirror		Agreed		
Bathroom	Incorrect	Toothbrush holder	Agreed		
		Top of the washing machine	It is generally less prone to mold growth compared to areas with high moisture retention		

Incorrect    Correct    Somewhat correct

In the subsequent phase, participants were invited to provide additional insights, ensuring that any overlooked information was captured. Some participants noted that furniture positioned near exterior walls, such as bed headboards, is particularly susceptible to mold growth. In the kitchen, 20% identified fruits, either inside the refrigerator or on countertops, as potential mold-prone items. Ceiling corners, especially those away from heat-generating appliances like refrigerators, were also mentioned, as the heat emitted by refrigerators can mitigate mold growth in their vicinity. Curtains, particularly in bedrooms, were another commonly suggested mold-prone area, along with ceiling corners across all three

rooms. Regarding the essential elements for mold formation, all participants agreed on humidity, temperature, nutrients, and spores as the key factors. However, some expressed concerns about the terminology being overly technical for general audiences. Most suggested replacing "humidity" with "moisture" and "temperature" with "cold surface" for better comprehension. Additionally, 10% highlighted potentially confusing incorrect responses, such as CO<sub>2</sub> and air pressure, which might be too abstract for users to understand. For optimal temperature ranges, the consensus was between 18 to 22 °C. In terms of humidity, participants acknowledged that maintaining levels below 60% can be challenging, particularly in

Auckland's climate. Instead, they recommended a target range of 40% to 60%.

Regarding strategies to mitigate mold growth, participants endorsed several approaches for inclusion in the game. Strategies such as wiping condensation off windows and walls were deemed effective in reducing mold risk. While keeping windows open is crucial, participants highlighted that prolonged openings during the day and night often lead to condensation due to temperature differences. Instead, each day, a 15-minute window opening period was suggested as a practical solution. Using lids on pots during cooking was another proposed strategy, though participants noted that it might not always be feasible depending on the prepared dish. Using extraction fans in bathrooms and range hoods in kitchens was emphasized as an essential strategy. Some participants also recommended simulating the use of venting dryers to the outside as an additional strategy. 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. However, 20% of them suggested separating the laundry from the bathroom and developing a dedicated room for it. Lastly, participants were asked whether simulating bedrooms and bathrooms for strategy application would be beneficial. Universally, participants endorsed this approach, emphasizing the critical importance of bathrooms as one of the most mold-vulnerable spaces in residential settings.

## 6 Conclusions and Further Research

This study validates the serious game's content, which is designed to educate the general public on mold prevention in residential buildings, contributing to the gap in research on the educational potential of gamification in air quality management. The findings indicate that mold-prone areas in residential settings, such as furniture near exterior walls, ceiling corners, and curtains, are critical to address. Additionally, participants highlighted the importance of understanding the key factors for mold growth, including humidity, temperature, nutrients, and spores, while suggesting more accessible terminology to improve general public comprehension. Considering Auckland's climate challenges, the study also confirmed optimal temperature and humidity ranges for indoor environments, with consensus favoring a target humidity range between 40% and 60%. Furthermore, several strategies to mitigate mold growth, such as wiping condensation, managing window ventilation, using extraction fans, and employing lids during cooking, were supported by participants and are recommended for integration into the game. Participants also emphasized the importance of simulating bedrooms and bathrooms in the game. In future studies, the research team will assess the effectiveness of the serious game, comparing it to a video-based instructional

method based on user engagement, motivation, and knowledge transfer.

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