Felines, Foragers, and Physicists: Supporting Scientific Outreach with Multi-Surface and Multi-Space Games

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ABSTRACT
We describe the design, development, and deployment of two scientific outreach games to support an open house event at an Institute for Quantum Computing (IQC) by an 11-member team of academics and practitioners over a one-year period. We overview our collaborative design process, the development of design goals aligned with facilitating scientific outreach during a one-day open house, and report on how successfully our final prototypes achieved those goals. We then reflect on implications for the use of interactive surfaces and spaces as a platform for scientific outreach, and in particular, the effectiveness of large displays as 'honey pots', the immaturity of technologies for creating interactive spaces, and extending the reach of outreach activities through technology.

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H.5.2. Information Interfaces and Presentation (e.g. HCI): User-centered design

Author Keywords
Games; Outreach; Large Displays; Mobile Devices

INTRODUCTION
The rapid adoption and evolution of interactive surfaces have provided an accessible, malleable, and engaging medium for scientific outreach. In particular, applications in scientific and educational outreach have been actively explored [9, 11], since interactive surfaces provide a familiar means by which lay audiences can be enticed to engage, interact, and ultimately learn about science. Furthermore, diversity in display size, display configuration (e.g., handheld, large format), and interaction modalities (e.g., touch, proxemics) enables scientific institutions to develop custom-built applications that better engage visitors with their research, personnel, and facilities.

Multi-surface and multi-space scientific outreach applications have the potential to help educate the public about local scientific activities, to act as a 'honey pot' and draw in otherwise uninterested audiences [5, 18, 20, 22], and to take advantage of the growing number of smartphones and tablets to engage individuals and extend an institution's reach beyond their physical space [12]. However, to effectively engage an audience with an institution's research, staff, and facilities, custom-built hardware and/or software is often necessary. And while software tools for gaming and multi-touch development (e.g., Unity) are available, there is a lack of guidance towards how they should be developed and deployed in practice to maximize their benefits for outreach applications.

Figure 1: We implemented two games to support scientific outreach. (top) Quantum Cats, an Angry Birds-like game that introduces guests to basic quantum mechanics. (bottom) Alice and Schrödinger's Excellent Adventure, a locative game that teaches guests about the IQC's research, staff, and facilities.

We describe the design and deployment of two applications developed over a one-year period by a cross-disciplinary team of 11 researchers and practitioners, aiming to educate and engage the general public with research at an Institute for Quantum Computing (IQC) during a one-day outreach event. As the surface applications were designed to support engagement with complex scientific material, we incorporated gameplay elements (e.g., puzzle-solving, item-collecting) for a more ac-

cessible and enjoyable experience. The first game, *Quantum Cats* (Figure 1, top), is similar to Angry Birds but was implemented on large multi-touch displays and later made available for download to personal smartphones and tablets. The second game, *Alice and Schrödinger's Excellent Adventure* (Figure 1, bottom), is a locative game designed with the intention to encourage exploration of the IQC's facilities.

We first describe our development process, which included a review of related work in the area of scientific outreach applications, an overview of our collaborative design process conducted with members of the IQC, and the development of design goals that guided the application development. We then describe each of the designs in depth, link each application's design to our stated goals, and describe use during the open house. We conclude with a reflection on our design process and goals, and discuss implications for the use of multi-surfaces and multi-space games as a platform for scientific outreach: the effectiveness of large displays as 'honey pots', the immaturity of technologies for creating interactive spaces, and extending the reach of outreach activities through technology.

SUPPORTING SCIENTIFIC OUTREACH

For decades, institutions such as museums, art galleries, and libraries have explored how new technologies can facilitate and promote engagement with their archives. For example, modern museums and art galleries often provide visitors with location-aware personal audio devices, or more recently smartphone applications [1, 16, 23], to augment their visiting experiences and provide details on an exhibit-by-exhibit basis as visitors move through a collection. Such use of technology to augment and enhance the visiting experience not only improves a visitor's experience by making the materials more accessible and enjoyable, but can also benefit institutions like museums through the development of brand and loyalty [25]. Thus, technology-enhanced exhibits have been developed for a wide range of topics such as science [3], natural history [15, 19], cultural learning [7, 8], and sustainability [2, 9].

A challenge in deploying these technologies, however, is that they often have limited interactivity, such as playing an audio track for each exhibit, and alone cannot make scientific, and often dry, materials more engaging. In response to this need, gamification, or the application of gaming elements to non-game domains [11], has recently been explored as a means of encouraging engagement with scientific outreach. For example, D'Angelo et al. [9] created a game to educate aquarium visitors about the dangers of overfishing. They noted that while such games could help to motivate interactions with educational or outreach exhibits, shallow learning experiences might be more appropriate. That is, outreach games may be most effective when they are designed for short playtimes of about 5 minutes, but encourage the player to continue exploring the subject matter at a later time. In this work, we explore the use of novel technologies, such as large interactive surfaces and spaces, as well as gamification to support scientific outreach. In particular, we explore the implementation of games on these platforms to support outreach activities at an Institute for Quantum Computing.

Scientific outreach activities, such as our open house event, also have requirements beyond those for typical exhibits. For example, besides providing educational value and engaging experience to visitors, the open house aims at promoting the hosting institute as a whole, thereby developing a stronger relationship with the outside community. These additional requirements have led to design criteria unique to scientific outreach activities, as discussed later.

Interactive Surfaces and Spaces

Many novel technologies, including interactive surfaces and spaces, have been explored as support tools for scientific outreach as they become technologically and economically feasible. For example, large interactive displays have been leveraged to provide interactive exhibit content for museum visitors [18, 20]. Similarly, emerging trends in mobile devices and augmented reality have been explored as a means of making physical spaces more supportive of outreach activities [1, 16, 23]. In this work, we explore using two technologies in these domains: large interactive displays, and location-aware mobile devices.

Interactive Surfaces: Multi-Touch Displays

Large interactive displays have been recognized by the HCI community as providing a number of opportunities and challenges for interaction in a public environments. For example, a large display often entices users to approach and engage with content [18, 20] and supports interaction through the now-familiar touch-interaction metaphor. Conversely, requiring users to interact publicly may deter some individuals from participating due to the risk of public embarrassment [5].

In the context of scientific outreach, a common theme is designing for short-lived, ephemeral interactions with large interactive displays. For example, Hornecker [20] noted that while their museum display attracted significant attention from guests, visitors were likely to spend only a few minutes exploring an exhibit, and thus only have a short time "to experience success ... and to understand the purpose, scope and properties" of the activity (p. 116). Similarly, D'Angelo et al. [9] reported that interactions with their fishing game rarely extended beyond a 5-minute timeframe, after which players moved on to explore other exhibits at the aquarium.

When designing our outreach applications, we paid careful attention to the benefits and limitations of large interactive displays. In particular, we designed a game to introduce quantum mechanics concepts and encourage further explorations with other open house exhibits. By deploying the game on a large interactive surface we encouraged brief interactions with the content, and expected visitors to then move on and explore other exhibits at the open house event. To further facilitate learning at the event, we designed complementary experiences using location-aware mobile devices.

Interactive Spaces: Location-Aware Mobile Devices

Another technology frequently explored to support outreach is a location-aware mobile device, such as a smartphone or tablet [1, 12, 16, 23]. These devices provide an opportunity to deliver additional materials to individuals on an on-demand basis, based on their location within an institution. For example, many art galleries use personal devices to provide information about

nearby artwork to a visitor. Similarly, evoGuide [17], a system for guided factory tours, provided visitors access to a variety of multimedia content, such as videos and textual descriptions of nearby objects that were otherwise available only to trained professionals wearing safety equipment. Recent work has explored benefits of providing such immersive experiences, particularly in the context of location-aware gaming with mobile devices (e.g., [4, 10, 14]), and help providing a 'socially safe' and engaging experience in public places [6].

When designing our own applications, we faced a situation similar to Hable et al. [17] where many research laboratories at the IQC were only accessible to trained personnel using proper safety equipment. To overcome this barrier, and to make the facilities and research more accessible to guests, we decided to develop a location-aware game that provided content via mobile devices as the guests explored the facilities. This location-aware game provided an opportunity to explore the IQC in more depth than our interactive surface game, and thus provided a complementary learning experience.

THE INSTITUTE FOR QUANTUM COMPUTING

The Institute for Quantum Computing (IQC) is a scientific research institute at a local university. As a research institute, the IQC's primary function is to facilitate research, and is home to about 25 faculty, 45 postdoctoral fellows, and 100 students exploring topics such as optics, nanoelectronics, nuclear magnetic resonance, and quantum sensors. As a university institution, the IQC also engages in outreach activities with the local community and hosts an annual open house event, where the general public is invited to meet IQC researchers and learn about their research.

The open house event features many outreach activities, including a tour of the facility which highlights many of the design features of the building that houses the IQC. For example, the "state-of-the-art facility is built to the most stringent scientific controls against vibration, temperature fluctuations, and electromagnetic radiation" [24]; a feature that would later impact our design since WiFi technologies rely on transmitted electromagnetic radiation. In addition to the building tour, featured activities include scientific demonstrations by graduate students and public lectures by eminent quantum physicists.

About a year before the open house event, our team was assembled to develop custom applications to support scientific outreach during the one-day event. While Human-Computer Interaction researchers were included on the team, no assumptions were made as to the specific technologies to be adopted for use in the project.

THE OPEN HOUSE PROJECT

Over an approximately one-year design cycle, we collaboratively developed a series of interactive experiences designed to inform, entertain, and educate open house guests about the IQC's personnel and research. The event was part of the university campus's larger Fall outreach activities, and featured scientific demonstrations by graduate students, a tour of the IQC facilities including laboratories, and guest lectures by world-renowned quantum physicists. As an outreach activity, the focus of the event was to develop engagement with the outside community, to make the research more accessible to non-scientists, and to foster an interest in science in visiting children and young adults who might one day become researchers themselves.

Our design team comprised 11 faculty, staff, and students from a games research group. Our student and faculty members brought perspectives from research backgrounds in English, Engineering, and Applied Health Science. They were responsible for the majority of the requirements gathering and initial scoping and design work on the project. Throughout this process, approximately 10 student outreach members from the IQC were consulted regularly for feedback on how to best engage guests with the interactive experiences. For example, multiple brainstorming and focus group sessions were held over the first 3-month period to determine what genres would be most effective in engaging guests with Quantum Mechanics principles. Approximately 6 months before the open house, two full-time developers and one artist were brought onto the project as dedicated development staff.

Design Criteria

Through our requirements gathering activities with IQC staff, we first identified past outreach activities at the IQC. For example, past open house events had featured a 'Plinko' game that was used to demonstrate the principle of quantum uncertainty. The game was played on a large display with input via a smartphone, but had many limitations: it demonstrated only a single quantum principle, was not strongly related to the IQC or its researchers, and was not perceived by IQC staff as being particularly engaging.

Using this feedback from the IQC administration and student outreach staff as design requirements, we developed a set of goals to inform and guide our design process:

(D1) Educational Value The primary function of the open house is to educate, to make IQC research accessible to the public, and to encourage exploration of quantum mechanics principles.

(D2) Personal/Local Information In addition to educating about quantum mechanics, the open house strives to teach about the IQC itself, including the research projects, personnel, and physical building. Where possible, installations should aim to highlight these more personal aspects of on-campus research.

(D3) Approachable and Accessible In addition to the above goals, installations at the open house should do so in a way that is approachable by a diverse group of open house guests, including children, individuals whose first language is not English, and those with physical disabilities.

(D4) Engaging One of the most significant challenges faced in previous open houses was making the (difficult) scientific content not only accessible to guests, but also engaging, and for guests to leave the event with a positive experience. An oft-cited goal was to have guests "Google 'quantum mechanics' " when they arrived home after the event.

(D5) Integrated The open house is a large event, spanning three research labs, and four floors of the IQC building.

Thus, IQC staff wanted to ensure that our installations were not a stand-alone experience, and worked to complement the other experiences taking place throughout the building.

(D6) Logistical Constraints A final design consideration arose from the IQC building's unique construction. Due to interference with nearby labs, the building does not have strong WiFi signals. Temporary wireless access points were provided in the lobby, but our design and development processes has to assume no WiFi access within the building.

We initially identified challenges in developing game applications that met all of these goals. For example, there are design tensions in making an installation that is both informative (D2) and approachable (D3). Similarly, integration (D5) across the entire open house may detract from engagement (D4) with a single installation. Thus, each of these goals was realized to a different degree in each of the subsequent projects.

THE GAMES

After gathering requirements and developing our design goals, we sought to determine which types of installations would best meet those goals. We followed a collaborative design process where our team consulted, brainstormed, designed, and tested iterations of each game in collaboration with IQC administration and outreach staff over a period of 8 months. Our first round of collaborative design, following our requirements gathering, explored the design space and identified the types of games that might best suit the open house with outreach staff. We eventually determined two installations to be developed:

Quantum Cats

Given the focus of the open house to educate and to make quantum computing research more accessible to the general public **(D1,3)**, the first installation was determined to be a classical game that would incorporate quantum computing aspects into its core mechanics. The motivation behind developing a game was that it would have broad appeal to a large group of guests, and would provide an approachable, accessible **(D3)**, and engaging **(D4)** experience while providing an opportunity to informally introduce quantum computing concepts to visitors **(D1)**. We hoped that this experience would spark interest in quantum computing, and foster engagement with other parts of the tour **(D5)** rather than be a stand-alone educational tool, and thus were not concerned with developing deeply educational experience.

Through a series of focus groups and seminars, we first proposed adaptations of classical arcade games, such as PacMan or Asteroids. Yet these suggestions did not receive much positive feedback. However, during a brainstorming session, IQC outreach staff proposed an "Angry Birds-like" game. This idea was well-received by IQC staff, administration, and our design team because of its familiar interface, and the opportunity to incorporate quantum mechanics into birds' flight properties. Over a series of design exercises we developed concepts for the quantum principles that should be incorporated into the game, and game mechanics that would be representative of the research at the IQC. In particular, three concepts that drove much of the IQC's research were identified: Super-positioning, Quantum Tunnelling, and Uncertainty.

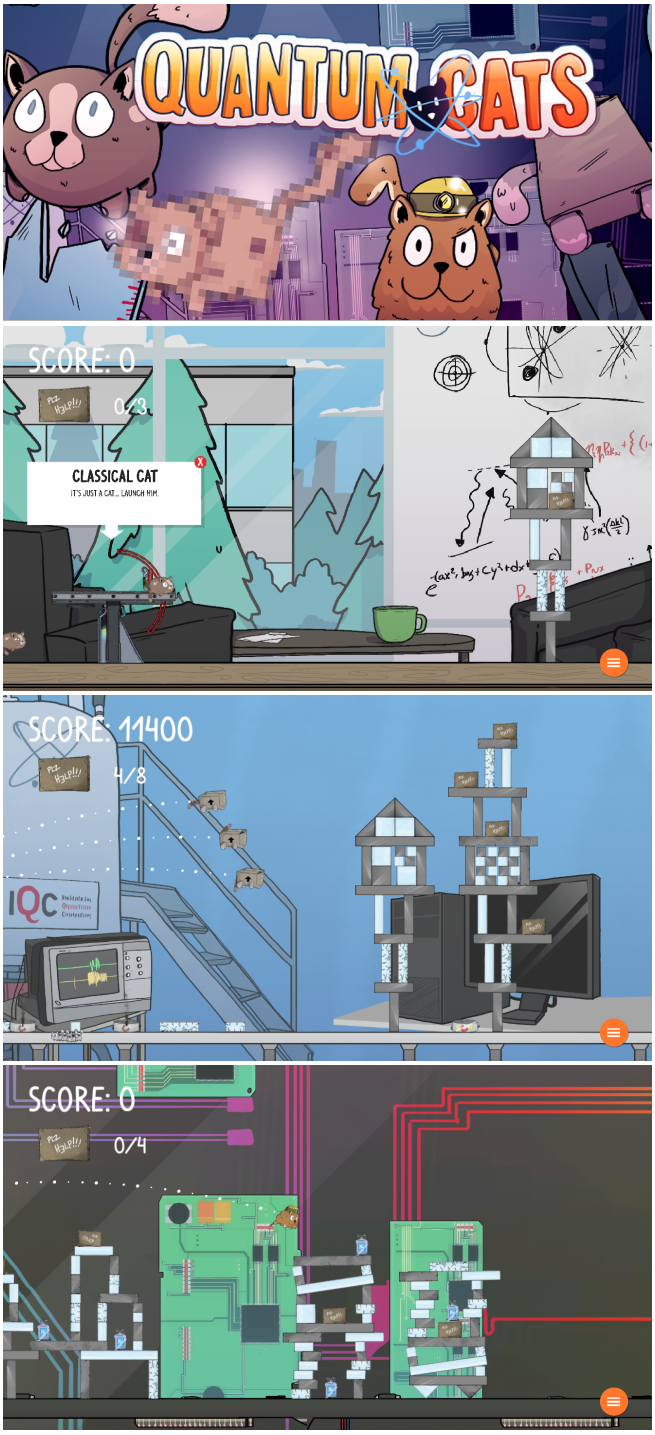

Figure 2: Quantum Cats, a puzzle game that employs many of the same mechanics and interaction metaphors as Angry Birds. **(Panel 1)** The Quantum Cats welcome screen, featuring each of the 4 in-game characters. **(Panels 2-4)** Players launch cats associated with quantum properties such as Uncertainty, Quantum Tunnelling, and Superposition to rescue kittens trapped in nearby boxes. As cats are launched on each level, obstacles have to be either avoided or knocked over.

Our game, called *Quantum Cats*[1] (Figure 2) is an Angry Birds clone that features four cats, who are launched using an electromagnetic catapult across levels to rescue the world's kittens (who are coincidentally trapped in nearby boxes). Each cat's game mechanics correspond to different quantum computing concepts: Classy represents classical physics and is a traditional ballistic projectile; Schrö represents superposition, and splits into three projectiles when fired, only one of which (picked by a tap) will ultimately strike a target; Digger embodies quantum tunnelling, and can pass through obstacles as he flies through the level; and Fuzzy represents quantum uncertainty, and flies through the level as a cloud of uncertainty, when tapped she will strike a randomly-determined nearby object at random speed. Each cat is illustrated in order in Figure 2, Panel 1. We created a series of 7 levels of varying difficulty to showcase each of the quantum mechanics and engage guests for an expected playtime of about 5 minutes.

Since existing research points towards brief interactions with game content [9, 20], the educational focus **(D1)** of Quantum Cats was on introducing quantum mechanics fundamentals to players through each of the cat's game mechanics (i.e., superposition, quantum tunnelling, uncertainty). Care was taken throughout the design process to represent these mechanics as accurately as possible. However, players were not expected to gain an understanding of their meaning through gameplay. Instead, the goal was to spark a player's curiosity, and, later on, engagement and conversation with exhibits and researchers. For example, by featuring different labs throughout the IQC, we hoped that players would later visit and inquire about their research and the quantum mechanics featured in-game.

Quantum Cats was developed in Unity 5[2] by our full-time development team over the 5-month period leading up to the open house. A benefit of developing in Unity was the ability to cross-compile for different platforms. We ultimately released the Quantum Cats app on the Google Play and iOS App stores, and could re-release on myriad additional platforms based on need. In addition to development in Unity, the game featured custom artwork by our in-house cartoonist with minimal text usage **(D3)**. The artwork was created to reflect the IQC and its research labs **(D2,5)**, particularly the Optics, Nuclear Magnetic Resonance, and Integrated Circuit laboratories.

To address our goals surrounding feasibility **(D6)**, the game was developed as a stand-alone installation on three 60" multitouch displays. Each display was mounted on a mobile, height-adjustable stand **(D3)** and equipped with a PQ Labs G4 infrared touch frame connected to an Android A300 series iStick computer[3] (Figure 1, top) to run the game.

Alice and Schrodinger's Excellent Adventure

Throughout our collaborative design cycles, we also identified a need to enhance the previous year's guided tour, to better describe the research conducted in-house and convey the uniqueness of the IQC facility's construction **(D2)**. We decided to develop a self-guided, locative, and augmented reality tour that

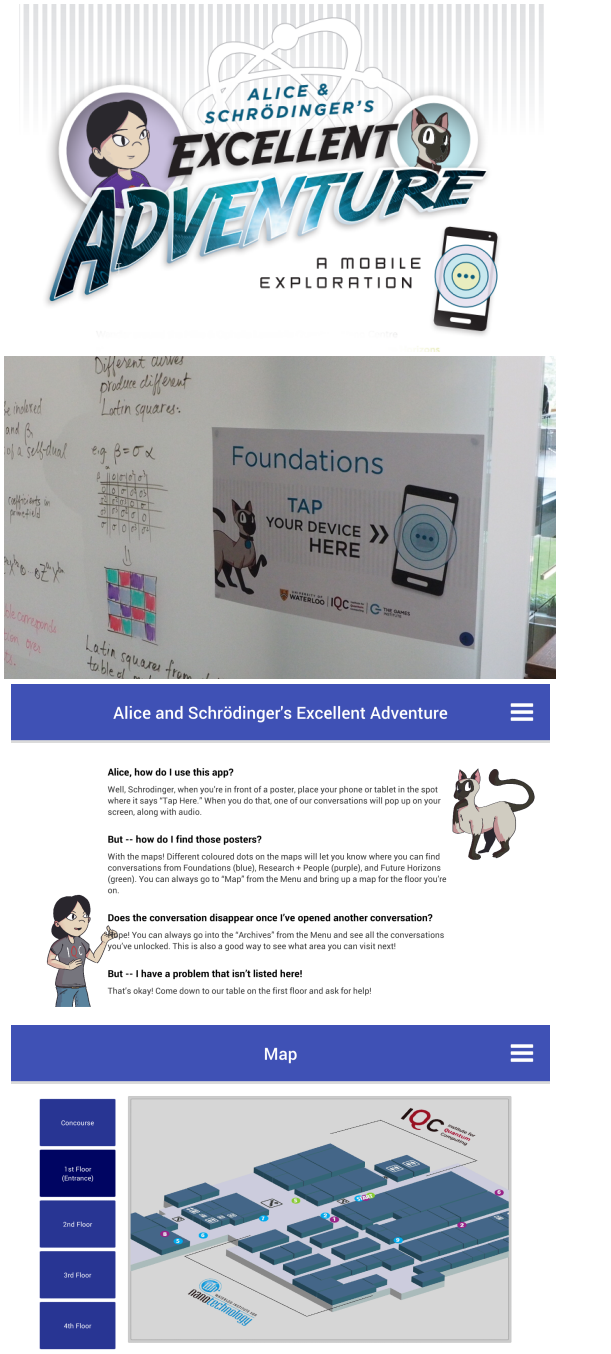

Figure 3: Alice and Schrödinger's Excellent Adventure is a locative game that encourages players to move around the IQC facilities. **(Panel 1)** Game's title screen. **(Panel 2)** Players scan NFC-enabled posters with their personal smartphone or tablet, or play the game using provided tablets attached to plinths located at key game locations. **(Panel 3)** As players move throughout the building, they reveal new conversations between a fictional IQC researcher, Alice, and her cat Schrödinger at each station. **(Panel 4)** An in-game map showing poster locations on one floor of the IQC's building.

[1] Available at http://quantumcats.ca
[2] http://unity3d.com
[3] http://multitouch.com/

would provide visitors an opportunity to explore the building at their own pace, and investigate their own points of interest in more depth than would be typically afforded by a guided tour. We sought to encourage visitors to explore the building in more depth, and support integration across the venue by connecting the locations with other open house events **(D5)**.

Alice and Schrödinger's key game mechanic relied on players scanning up to 34 interactive posters placed around the building with a smartphone or tablet's built-in NFC reader (Figure 3, Panel 1). As players scanned each poster, they experienced conversations between Alice, a fictional IQC researcher and her cat Schrödinger (Figure 3, Panels 2 and 3). Thus, the game leveraged a 'foraging' metaphor whereby players were free to move around the building and complete as few or as many of the locations as they wished. These locations were indicated as in-game maps (Figure 3, Panel 4), and were revealed to players as 'achievements' that were unlocked as they visited each location and experienced the associated dialog. In addition to experiencing each conversation in text, voice actors were hired to record a full version of the game, improving accessibility and engagement **(D3,4)**.

The 34 game posters were organized around 3 themes: Foundations, Research and People, and Future Horizons. The Foundations theme focused on providing information about the IQC facility; the Research and People theme focused on providing information about the people working at the IQC; and the Future Horizons theme provided in-depth details about research conducted in specific labs, and the anticipated practical implications of quantum computing. Each of the three themes had a total of 11 posters, with one 'Start' poster in the concourse.

Unlike Quantum Cats, the mobile nature of the adventure meant that logistical constraints of the IQC also needed to be considered in our game design **(D6)**. In particular, the physical design of the IQC facility prevented the use of WiFi throughout the building, and required all content to be loaded onto the devices prior to engaging on the tour. To enable players to use their own devices for the tour, we set up a local WiFi access point in the building's lobby and encouraged visitors to download a local copy of the app before exploring the building. For those individuals who wished to play the game but did not own a compatible device, we provided two additional options: 1) 20 Android Nexus 7 tablets were available to sign out from the lobby with pre-installed copies of the game, and 2) a series of plinths were installed throughout the building at key game locations with a tablet set to permanently display the associated portion of dialog. However, regardless of which device was used to play the game, the building's WiFi limitations impacted our ability to monitor progress through the tour, or to collect usage data over the course of the open house.

As with Quantum Cats, the game was developed by our team in Unity 5. However, due to restrictions on use of NFC technologies in iOS, the game was only available to Android devices.

EXPERIENCES AT THE OPEN HOUSE

In the lead-up to the open house event, we found that IQC administration staff were excited about the development of our custom applications, and the potential to provide a new, engaging, and accessible experience during the open house event. In preparation for the event, the IQC invested additional marketing resources in creating Quantum Cats-themed merchandise that would accompany and better promote the game, including t-shirts, science kits, and a series of collectible stickers that featured the four Quantum Cats. The t-shirts and science kits were available for purchase at-cost at a nearby merchandise table, while the stickers were handed out for free next to the Quantum Cats displays.

Furthermore, many resources were dedicated to promoting the event. For example, the `quantumcats.ca` domain was purchased, and a companion website was developed to enable interested visitors to further explore the game and its content.

Finally, during a soft launch event at a nearby museum approximately two weeks prior to the open house, discussions with reporters generated additional interest and a request to feature the Quantum Cats game in an upcoming article. Based on this interest a decision was made to make the Quantum Cats game available for download as an app. While this decision came late in our development process, we felt confident that we could deliver the cross-compiled applications in-time for the event, due to the flexibility afforded by Unity's development environment. Ultimately, Quantum Cats was available on Google's Play Store on the day of the open house event. It was however not available on Apple's iOS App Store until a week later due to delays in the approval process.

We now reflect on our experiences at the open house event, and in particular how the two games helped support scientific outreach activities. Due to nature of the open house, more traditional evaluation methods, such as video recordings and on-site interviews, were not available to us. Instead, our presentation of results focuses on observations and field notes, event and post-event usage and download numbers, and post-event discussions with IQC staff.

Quantum Cats

Quantum Cats was largely considered a success by IQC staff and administrators. Since the game was played on our own large displays, we were able to collect some usage data from the event. Our logs showed that over the course of the day more than 2,400 cats were 'launched' in-game, representing an average rate of more than 8 cats per minute. This level of use exceeded our expectations for the event, but matched observations by the researchers throughout the day; the three displays running identical copies of the game were a popular destination during the open house, particularly for younger children and families (Figure 4).

While we had intended for the Quantum Cats play experience to be short in duration, we noticed that many players stayed long enough to attempt most, if not all of the available levels. Many players stayed until they were able to complete each level before moving on to a new exhibit. In one case, a parent ready to leave the open house event and head home literally dragged their child away from the display.

We did not observe many usability issues with the game over the course of the event, however two issues were identified. First, the Uncertainty Cat was notoriously difficult to use, and

Figure 4: Quantum Cats was played throughout the day by visitors. In front of the displays, Quantum Cats-themed stickers were handed out to visitors at no cost.

Figure 5: An open house volunteer demonstrates how to scan an NFC-enabled poster for Alice and Schrödinger's Excellent Adventure using a guest's smartphone.

we observed that players frequently did not understand that to 'activate' the cat's ability one needed to tap the screen. This usability issue was identified as a priority in our next development iteration. Second, the IR touch frames that we used for the installation occasionally started generating spurious 'ghost' touch points. While we were unable to diagnose the issue on-site, we found that rebooting the iStick hardware resolved the issue temporarily; a procedure we followed throughout the day as needed to keep the games up and running.

In the week following the open house, Quantum Cats was downloaded more than 5,000 times on the Google Play Store, vastly exceeding the approximately 300 in attendance at the event. These downloads can be attributed in part to open house guests downloading the app while on-site or when returning home. However, more significantly the app was featured on various media such as `phys.org`, a leading scientific research and technology website with a large audience. We discuss this exposure later, in our Implications for Design section. Unfortunately, since the game did not launch immediately on Apple's iOS App Store, only 300 downloads were registered for iOS devices two weeks after the event.

Alice and Schrodinger's Excellent Adventure

As previously mentioned, poor WiFi reception within the building limited the amount of data we could collect (e.g., real-time usage) for the locative game Alice and Schrödinger's Excellent Adventure. These limitations meant that all content was downloaded to a player's tablet or smartphone prior to gameplay, and we had to rely on experience sampling over the course of the open house to determine how well the game served its purpose of providing a deeper learning experience during the event.

While we had made the application available for download prior to the event, based on our observations, however, very few visitors installed and used the application. Inspection of our Google Play account confirmed this hypothesis, and only 12 individuals installed the application to their personal device during the event. Nevertheless, 38 visitors signed out one of the tablets from the front desk, and played the pre-installed game using the borrowed tablet.

We attribute the relative shortage of players to four possible issues. First, many visitors did not understand that the posters were connected to a game, and never sought to download the application or sign out a tablet. Second, due to restrictions on NFC usage, our application was not available on the iOS platform, and was restricted to be used by individuals with an NFC-equipped Android device. This restriction likely limited users to about 60% of visitors, based on recent adoption numbers [13]. Third, we encountered a number of users who had downloaded the app to an Android device but did not have the NFC functionality enabled; in these cases we assisted those players that we could, but some may have simply given up. Finally, some individuals may not have found the self-guided tour to be engaging or worth the effort to download, or may not have had an interest in learning about the IQC.

We were, however, able to inspect the game state of the 38 players who borrowed an Android tablet on the day of the event. While some took the time to explore all 34 posters, most explored only a handful of nearby points. One usability issue that arose from a conversation with one 'Completionist' player was that the in-game numbering the posters was extremely inefficient to visit in-order (though not required), which took the determined player an extraordinary long time to complete.

REFLECTIONS ON DESIGN GOALS

We strove to balance scientific learning with creating engaging, technology-enhanced, and fun exhibits for the IQC's open house event. In developing Quantum Cats and Alice and Schrödinger's Excellent Adventure, we worked directly with IQC staff to develop a set of six design goals to inform our design process. We also carefully considered how interactive surfaces and spaces could serve the event, and placed an emphasis on developing applications that addressed the design goals identified through our initial consultations with the IQC. We now reflect on some of the tensions that arose between these design goals as we progressed through the development process, how we resolved those tensions, and the overall outcome of our design process.

Educational Value (D1) vs. Engagement (D4)

Perhaps the most immediate tension that we tried to address was the issue of creating a Quantum Cats game that was both educational **(D1)** and engaging **(D4)**. We acknowledged early on, in line with other outreach research [9, 20], that players were unlikely to spend more than a few minutes playing the game, and thus were able to focus on delivering a "superficially educational" game that aimed to introduce the player to various fundamental quantum mechanics concepts, rather than develop in-depth knowledge about one particular concept.

The choice to leverage Angry Birds' gameplay helped significantly in supporting ephemeral play sessions for a number of reasons. For example, the game remained extremely popular amongst the general public and allowed for many people to 'walk-up-and-play', overcoming existing research challenges such as interaction blindness [21]. The physics-based gameplay also helped scaffold players' advancement through each of the included quantum mechanics concepts, starting with classical Newtonian physics and then moving on to more advanced concepts such as Superposition, Quantum Tunnelling, and Uncertainty. Usage numbers collected during the event suggested that our design was engaging.

However, assessing the educational value of the game was more difficult, particularly for the 'shallow' learning experience that we targeted. In post-event discussions with IQC outreach staff there was a general agreement that the game had achieved its goals, and administration staff decided to invest additional resources into development for Quantum Cats. In particular, they extended the development team's contract and approved the creation of new artwork for the game. While specific design goals are still in development for this iteration of the software, initial discussions have focused on how additional educational content could be introduced to gameplay, particularly for those who downloaded the game to a personal device. We interpret these outcomes as a tacit acknowledgment of both the achievement of our initial goals surrounding engagement, but also that outreach is an ongoing process.

Personalization (D2) vs. Logistics (D6)

On the other hand, our work on Alice and Schrödinger's Excellent Adventure largely focused on addressing tensions between creating a personalized tour of the IQC's facilities and research **(D2)** and logistical constraints at the event **(D6)**. In particular, we identified issues around WiFi connectivity early on in our design process and worked to create a locative game that would work without internet connection. We took inspiration from personal curator devices used in museums, and incorporated an 'item-collecting' gameplay element where visitors 'unlocked' dialogs by physically visiting locations in the IQC.

However, Alice and Schrödinger's Excellent Adventure was not played by many visitors at the event; a shortfall we attribute, at least in part, to the logistics surrounding deploying games to personal devices in a setting without reliable wireless connectivity. Our observations of players at the open house event pointed to at least three contributing failure points: 1) that the application (70MB) must be downloaded in its entirety to a personal device, 2) that the NFC functionality must be enabled on the personal device, and 3) that the IQC had limited resources to distribute tablets to visitors.

In retrospect, we underestimated the degree to which these relatively small logistical issues would interfere with providing a personalized tour of the facility. We had expected a mature ecosystem on which to deploy a locative game, and that users would be familiar enough with their personal smartphones to manage NFC functionality. Instead, we found that these technically minor issues were significant barriers to visitors playing our game. While we had anticipated these barriers to some degree, and that some visitors would benefit from signing out a tablet for the tour, the IQC's resources were limited to purchasing 20 tablets to loan out during the event. We discuss the implications of this tension in the next section.

IMPLICATIONS FOR DESIGN

Our results provided an opportunity to reflect on our design process and outcomes, and discuss implications for the design of surfaces and spaces that support scientific outreach.

Can a Honey Pot Encourage Pollination?

Our design experience and review of the literature point to interactive surfaces as supporting relatively short-lived, engaging interactions. If this is the case, a number of implications for the design and value of large, interactive surfaces arise – particularly in outreach settings such as those explored in this work. For example, how can the monetary and development costs for installations such as Quantum Cats be justified as educational tools? In justifying the often high development costs, institutions such as museums and art galleries, which often are working with constrained budgets, must answer the question of whether such large display installations provide sufficient value to justify their expenses.

One potential answer to this question is engagement. The 'Honey-Pot' effect of large displays is well documented in the literature [5, 18, 20, 22], and large displays are often able to attract an audience to important content. This effect is particularly appealing for scientific outreach applications, and for example, was a critical factor in the decision to continue development for Quantum Cats. However, what remains to be shown is whether a corresponding '*pollination*' effect may also take place. That is, can nearby or associated attractions also benefit from the 'honey pot' effect surrounding a large display.

While we set out to design for this effect in our work, we were unable to perform a formal study to verify our success, and leave answering this question to future work.

Creating Interactive Spaces

We developed Alice and Schrödinger's Excellent Adventure with the hope of providing a deeper, more personal tour and learning experience at the open house event. While Unity provided comprehensive support for most aspects of game development, we found that a number of technical/logistical issues were obstacles to the development of our interactive spaces. In particular, our work points to some very practical difficulties in creating locative content that is available to all attendees, and can be integrated with surrounding exhibits. For example, even though NFC readers have been integrated with many smartphones for a number of years now, they are not consistently available on all devices, and in many cases are disabled and difficult to enable via nested or hidden settings.

We settled on NFC to determine a player's location because it provided a simple interface/interaction mechanism, could be embedded in other artefacts, and was natively supported on many Android devices. Other technologies such as QR Codes, iBeacon, or camera-based toolkits offered different combinations of trade-offs which we felt were less appropriate for this application. Our experience suggests that the technologies available to create these experiences have yet to mature, and there is an opportunity for research to provide support to developers, and perhaps more importantly, to end users.

Extending an Event's Reach

Our experience with Quantum Cats illustrates the potential of custom-built games not only to encourage learning on-site, but also after visitors had left the open house event, and to individuals who were not able to attend at all. Data from our Google Play account suggested that Quantum Cats was installed on more than 5,000 devices in the week following the event, compared to the approximately 300 guests that attended the event in-person. Even downloads from Apple's iOS App Store reached more than 300 unique devices, despite the launch being delayed by more than a week.

Enabling visitors to download their own souvenir copy of the app provided a means of making these experiences available to them after the event had taken place, an advantage not mentioned in previous research around companion apps [12], and was positively perceived by IQC administrators. However, the capability to download and install the app was only included later in our design phase due to concerns around compatibility and testing on the wide variety of expected devices, particularly within the Android ecosystem. The decision to upload versions to app stores and allow installation on personal devices was only feasible due to the flexibly afforded by Unity's development environment, and the capability to port code quickly and easily. In addition, our lead developer had the foresight to anticipate that the user interface may need to scale to different display sizes, thus only minimal revisions and testing were required for mobile devices.

Following the open house event, IQC administration expressed interest in continuing development on Quantum Cats, which we interpret as largely arising from the media interest and downloads of the game following the event. This new direction has, not surprisingly, led to different design criteria as compared to a large interactive display for a one-day event. For example, the expected duration of play, the much smaller form factor, and the further educational value the game provides; some of which are reflected in the reviews in the app stores.

CONCLUSION

We described the design, development, and deployment of two scientific outreach games for a local Institute for Quantum Computing (IQC). By combining surface technologies and gameplay mechanics, we created a touch-centric game for both large displays and personal devices. We also created a locative game designed with the intention to encourage visitors to physically explore the IQC's facilities, research, and staff. Our collaborative design process allowed us to work with stakeholders in establishing six design criteria that guided the design and development, leading to a successful deployment on the event date, and opportunities for further developments. By reflecting on our design experience, we also discussed tensions between educational value and engagement, and personalization and logistics. Finally, we discussed implications for the design of interactive surface and space applications to support scientific outreach.

Our work highlights both the potential and the challenges to the use of interactive surfaces and spaces as platforms for scientific outreach. Large interactive surfaces provide an engaging, easily understood platform on which complex materials can be presented to a lay audience, but may only be used for a few minutes at a time. On the other hand, locative games provide an opportunity for learning over longer periods, and engagement with more complex materials, but may be inhibited by logistical and hardware constraints related to personal devices. We see multi-surface and multi-space games as a promising vehicle to engage the public with scientific outreach activities, and foster lasting interests beyond a day-long event.

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