VISION-BASED AUGMENTED REALITY FOR FORMAL AND INFORMAL SCIENCE LEARNING

by

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A thesis submitted in conformity with the requirements for the degree of Master of Information
Graduate Department of Faculty of Information
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Abstract

Vision-Based Augmented Reality for Formal and Informal Science Learning

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This thesis explores the application of vision-based augmented reality in formal and informal educational environments. It focuses on the common practices, concerns, and priorities that developers and content creators in each environment frequently encounter, offering insights into how these experiences are changing with the incorporation of new digital media technologies and the hardware platforms that support them. The research outlined in this thesis uses qualitative methods, assembled around a series of twelve hour-long interviews with highly-experienced educators, developers, researchers, and designers, and analyzed using a grounded theory approach. This thesis introduces original research about the role of computer vision-based augmented reality as an educational medium, a topical discussion in information studies, museum studies, learning sciences, and a number of other fields, and makes a theoretical commitment to addressing the ways that material and virtual objects come to interact meaningfully in a variety of learning environments.
I wonder why. I wonder why.
I wonder why I wonder.
I wonder why I wonder why
I wonder why I wonder!

- Richard Feynman
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I am fully committed to the ideal of building collaborative relationships to promote and support this type of research, which couldn’t have been undertaken without the support of colleagues and friends who have given me advice, provoked curiosity, and spurred new directions.

A copy of this thesis, as well as supplementary documentation and material, can be found on my personal website: http://losingtime.ca.
# Contents

1 Introduction ........................................... 1  
   1.1 Research Description ........................................... 2  
   1.2 Thesis Statement ........................................... 4  
   1.3 Motivation ........................................... 7  

2 AR State-of-the-Art ........................................... 9  
   2.1 Vision-Based AR Development Frameworks ......................... 10  
   2.2 Projects and Examples ........................................... 14  

3 Literature Review ........................................... 21  
   3.1 Digital Media, Augmented Reality, and Science Education ................. 22  
   3.2 Materiality and Virtuality ........................................... 23  
   3.3 Narrative and Storytelling ........................................... 28  
   3.4 Bringing Together the Formal and Informal ......................... 32  
   3.5 Critical Information Design ........................................... 34  
   3.6 Reconfiguring the Interface ........................................... 36  

4 Methodology ........................................... 39  
   4.1 Data Collection ........................................... 39  
   4.2 Participant Selection ........................................... 40  
   4.3 Participant Descriptions ........................................... 43
5 Analysis of Interview Data

5.1 Grounded Theory

5.1.1 Coding Scheme

5.1.2 Explanation of Codes

5.1.3 Summary

5.2 Addressing the Thesis Positions

5.2.1 AR as a Teaching Tool

5.2.2 Bridging the Formal and Informal Development Communities

5.3 Emergent Themes and Discrepancies

5.3.1 Curriculum

5.3.2 Assessment

5.3.3 Personal Devices

5.3.4 Educator and Learner Comfort with Technology

5.3.5 Materiality, Simulation, and Interaction

5.3.6 Social Media - Social Collaboration

5.3.7 Gaming and Gamification

5.4 Shifts and Tensions

5.4.1 Design Considerations

5.4.2 Groups, Institutions, and the Public
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4.3 Which Way Forward?</td>
<td>99</td>
</tr>
<tr>
<td>6 Case Study - Floops</td>
<td>101</td>
</tr>
<tr>
<td>6.1 Design</td>
<td>102</td>
</tr>
<tr>
<td>6.2 Critical Making</td>
<td>107</td>
</tr>
<tr>
<td>7 Findings</td>
<td>109</td>
</tr>
<tr>
<td>7.1 Summary of Findings and Recommendations</td>
<td>109</td>
</tr>
<tr>
<td>7.2 The Potential Long-Term Viability of AR</td>
<td>113</td>
</tr>
<tr>
<td>7.3 Bridging the Museum and School Experiences</td>
<td>116</td>
</tr>
<tr>
<td>7.4 Narrative, Content, and Curriculum</td>
<td>120</td>
</tr>
<tr>
<td>7.5 Future Scenarios and Technology Convergence</td>
<td>123</td>
</tr>
<tr>
<td>8 Future Work</td>
<td>125</td>
</tr>
<tr>
<td>8.1 Ethnographic Approaches</td>
<td>126</td>
</tr>
<tr>
<td>8.2 Culture and Socioeconomics</td>
<td>128</td>
</tr>
<tr>
<td>8.3 Other Media</td>
<td>132</td>
</tr>
<tr>
<td>8.4 Studying AR as a Viable Learning Technology</td>
<td>134</td>
</tr>
<tr>
<td>9 Final Remarks</td>
<td>137</td>
</tr>
<tr>
<td>Bibliography</td>
<td>140</td>
</tr>
<tr>
<td>A Legend</td>
<td>155</td>
</tr>
<tr>
<td>B Glossary and Terms</td>
<td>156</td>
</tr>
<tr>
<td>C Interview Questions</td>
<td>158</td>
</tr>
<tr>
<td>D Illumine</td>
<td>160</td>
</tr>
<tr>
<td>E Experiences</td>
<td>162</td>
</tr>
</tbody>
</table>
List of Tables

4.1 Number of potential interview participants contacted, identified by primary and secondary occupations. ................................. 42

4.2 Mode of Interviewing ......................................................... 46

5.1 Code Frequency: Code indicates the code word used to tag a phenomenon or theme. Frequency indicates how often the code came up in the set of twelve interviews. Number of Interviews indicates the number of interviews that the specific code turned up in. ........................................... 53
List of Figures

3.1  An updated representation of Milgram’s Virtuality Continuum. . . . . . . 25

5.1  The RQDA coding interface showing emergent codes from interview tran-
scripts. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 54

5.2  Coding an interview transcription in RQDA. . . . . . . . . . . . . . . . . 55

6.1  A trackable image in Floops . . . . . . . . . . . . . . . . . . . . . . . . 104

8.1  The Google Glass Project, as worn by a model. . . . . . . . . . . . . . 133

E.1  A poster I presented at the 2011 InPlay Conference describing the ENroute
project. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 166
Chapter 1

Introduction

Growing up in a rural backwater, my early education was split between two distinct experiences. The first involved trying to understand how the objects of my immediate world worked by taking them apart, building them anew, and exchanging the frequently odd and novel creations with my friends. The second involved being taught by often well-intentioned teachers whose pedagogical approaches and delivery styles were dependent on classroom management more than student collaboration and engagement. My extracurricular education was an interactive and self-guided experience, where I came to understand what made plants grow, planets rotate, or engines work by making things and discussing their intricacies with friends in the backs of barns, sheds, and school buses. I found little space to exercise my imagination in school - an experience that was certainly not unique.\(^1\) Perhaps somewhat unfairly, I came to see all schools as representative of unwavering, tired pedagogy, where education is “delivered” and students are “formed” to fit, like fence posts in an endless row of post holes, into the broader society. This idea began germinating early in my education, and was cultivated throughout the secondary school years. In 1994, however, a ripple appeared in the fabric that enveloped my friends and I. My school library, which had recently acquired a computer, connected

\(^1\)A handful of critical pedagogy theorists have addressed this subject. Notable among them is Weiner (2007, 2009) and Rautins and Ibrahim (2011).
to the internet. It felt like the outside world had finally arrived, and with it the fecund imaginations of my close friends and I were unleashed.

Looking at the place of new and digital media\(^2\) in education, we are very likely at the base of an exponential growth in both adoption and implementation.\(^3\) This thesis describes both a scholarly and personal exploration of strategy shifts in curriculum, policy, and attitude toward collaborative content development that the introduction of cutting edge new and digital media technologies into science education is encouraging. I am engaged with this at the ground level as both a scholar and developer. I am, however, also engaged as a parent, for whom the education of my young children is a foremost concern. Most important, though, I am curious about cognition and its relationship to interaction across multiple planes. By approaching this research through a few disciplinary lenses, and attempting to ground it in practical application - by building things and engaging with other builders in the process - I have made it meaningful to me in a very deep and lasting way, and look to provide explanations and descriptions which prove meaningful to others interested in this subject.

1.1 Research Description

At its root, the research described in this thesis uses qualitative methods to explore questions about the development of vision-based augmented reality - a technology that has

\(^2\)New media is a rather broad, encompassing term that does not necessarily require a digital component, although it is often conflated with digital media. It describes communications technologies that diverge from older, top-down, directed, analog media toward delivery that is convergent, manipulable, and enables users to interact with information. Digital media, on the other hand, is more closely related to technologies that enable digital data storage or processing. See Appendix B - Glossary and Terms for more on the distinction between digital media and new media. Throughout this thesis, I will be using both terms, although I am more partial to describing the research that I’ve undertaken as having to do with digital media, as there is a component of digital storage that is both crucial and interesting to how a technology like vision-based augmented reality works.

\(^3\)Roberts and Foehr (2008) analyze statistics related to digital media use by youth. Wei and Hindman (2011) note that few studies compare the differential effects between new media and old media use on knowledge gain, and seek to provide policy recommendations for addressing disparities in digital media adoption and use. Jenkins (2009) supports the notion that new media is a crucial and expanding territory that needs to be reckoned with.
only recently become publicly accessible - for formal and informal educational environments. Computer vision, very generally, is a broad field that deals with the processing of so-called “real world” images and other data in order to translate them into numerical or symbolic digital representations. In essence, it is a means for sensing devices, like the camera on a mobile phone, to recognize material objects and reference them against databases of recognized objects that can be used to connect virtual content with the material object. Augmented reality (AR), as distinguished from virtual reality on one end, and the authentic material world on the other, is a digital media technique where a live view onto a real world environment is augmented or enhanced by computer-generated sensory information. This often employs visual information, but also frequently delivers auditory or other perceptual output. Kerawalla et al. (2006, p. 164) describes AR like this: “[While] VR [Virtual Reality] can immerse the user so that they cannot see the real world around them, AR allows the user to see a real world that is supplemented with virtual elements... the viewer can simultaneously see the real world and the added virtual elements.”

While this thesis also more broadly looks at the use of other digital media technologies to enhance existing pedagogy, it does this by exploring the common practices, concerns, and priorities that educators, developers, content creators, and curators in classrooms and science museums encounter when introducing these kinds of technologies. The place for augmented reality as an educational medium is an emerging theoretical discussion in both museum studies and science education, and this research seeks to address the ways that material and virtual objects come to interact in meaningful ways through the use of this kind of technology. There is a wealth of literature in wide-ranging disciplines,

\footnote{While some companies and developers refer to this technology as image-based augmented reality or computer vision-based augmented reality, I will be referring to it as vision-based augmented reality hereafter.}

\footnote{Rosenfeld (1988) provides a good introduction to the fundamental theoretical principles of computer vision, while Szeliski (2010) is a comprehensive introduction to the uses of computer vision today. The latter is available for free, and updated regularly, at http://szeliski.org/Book/drafts/SzeliskiBook_20100903_draft.pdf}
from philosophy to anthropology, that ponders the role of material objects in learning environments (Pearce, 1990; Knorr-Cetina, 1997; De Jong et al., 2010), and researchers are now frequently encountering greater opportunities to assess the role that virtual objects can play alongside their so-called material counterparts. Pels et al. (2002, p. 3) write:

The world of things which we routinely inhabit has of course always extended far beyond raw tangible matter and ‘really existing’ realities into the vast realm of the abstract, the invisible, the imaginary, and the virtual. In a culture which favours bricolage, simulation, performativity and acting-as-if, we have increasingly learned to calculate and play with this radical indeterminacy between the real, the not-so-real and the imaginary.

This thesis is a point of entry into this dialogue as regards a specific technology that could be a true game changer if the general public latches on to truly revolutionary technologies, like Google’s Project Glass, that have existed in the minds of science fiction authors for decades but, until recently, have not been tangible in any real public sense.6

1.2 Thesis Statement

The research in this thesis explores the following positions:

- Vision-based augmented reality has the potential to be an effective tool in the arsenal of educators using digital media in both formal (classroom) and informal learning environments. While I am interested in informal learning generally, I am situating science centres in the informal world here. This is consistent with both the opinions of a number of my interviewees, as well as Dierking and Falk (1994),

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6More information about Google’s Project Glass, which will see augmented reality implemented in a hands-free, head-mounted display resembling futuristic eyeglasses can be found here: [https://plus.google.com/111626127367496192147](https://plus.google.com/111626127367496192147), and it will be discussed at greater length in later chapters.
Gerber et al. (2001), and Hofstein and Rosenfeld (1996, p. 88), who write: “There is no clear agreement in the literature regarding the definition of informal science learning. Part of the problem is that such learning can take place in many environments, e.g., natural history parks, geological sites, zoos, botanical gardens, industry, science museums and nature centres.” The more publicly familiar location-based augmented reality\textsuperscript{7} has a number of interesting and engaging uses, but due to a host of technical constraints, it does not have the same potential for enhancing science education that vision-based augmented reality does in bounded interior environments, where spatial context awareness is a challenge.

- Because vision-based augmented reality is a technology that appears well-suited for both formal and informal science education, developers, content creators, teachers, exhibit designers, and curators - stakeholders from formal, informal, and development communities - have opportunities to leverage their shared goals and skill sets to create effective uses of this technology. In doing so, they can learn from the mistakes and successes of each other, engaging more frequently across boundaries as digital media development practices mature and become more open. At their disposal is a growing body of resources supported by a community composed of game developers, commercial designers and marketers, artists, and others.

By focusing on these two themes - the value of vision-based AR as an educational tool; and opportunities for collaborative exchange between the informal and formal worlds around digital media introduction - this thesis can lead to improved collaborative design practices in science education development, and subsequently may provide better understanding of how vision-based augmented reality can be developed successfully in both arenas.

Ultimately, I hope that it might illuminate whether designs that are constructed for

\textsuperscript{7}Location-based augmented reality frequently relies on GPS-enabled smartphones - GPS stands for global positioning system, a satellite-based positioning system that uses receivers, common on most new mobile devices - to determine one’s location in the world and provide virtual content anchored to that location.
museums can be effectively ported over to classrooms and vice versa.

In addition to exploring issues around these two themes, my methodological approach has been designed to address the following questions:

- How does new digital media translate across formal and informal boundaries? Is it possible to connect (or reconnect) formal and informal education through the use of technology that engages learning activities in the interstitial spaces between the two?

- Furthermore, are the findings of this research generalizable across the different disciplines it engages, and do they need to be to provide recommendations for better development practices?

- What kind of epistemological assumptions are made about the design and implementation of learning objects (material or otherwise) in experimental educational technologies?

- Because of scalability, cost, complexity of design, and a host of institutional issues, informal learning environments appear to be more equipped to incorporate experimental and bleeding edge digital media than formal ones. Is this an accurate assessment, and how can it be measured?

I do not intend for this research to find universal epistemic truths about how people - or children specifically - learn. If anything, I think that it may elaborate on the impact that introducing experimental techniques or digital media technologies is currently having on education and museum studies, as well as at a broader cultural level - but I am not setting out to establish laws or criteria about how this should happen. Ultimately, I am interested in exploring not just whether AR is a viable technology in learning environments, but also whether new digital media-based experiences have the same force as analog, engineering-based physical experiments or artifact-based exhibits.
1.3 Motivation

This research seeks to contribute to a growing understanding of how digital information can be classified, and how it might differ from traditional, more analog forms and media of information in learning and meaning-making contexts. In many ways, it has to do with our reliability and trust in the delivery and authorship of information in that a number of the questions I am motivated by deal with who controls and presents information, how this information is verifiable, and the points at which virtual information objects can be used to invoke new and unique thoughts, memories, and meanings irrespective of historical or physical accuracy. I am especially interested in exploring questions around who creates and perpetuates “knowledge” in formal and informal education.

While there is an abundance of existing research in the fields of electrical engineering and computer science on the use of AR in commercial application, there appears to be a dearth of literature seeking to bridge relevant and topical AR research from the fields of information, education, anthropology, and science and technology studies with more technical research coming from the aforementioned ones. This research aims to help fill in that gap, and seeks to contribute to the growing dialogue initiated by groups such as the Ontario Augmented Reality Network and myriad other partnerships between academic institutions and industry working in this area, like Georgia Tech’s GVU or the University of Canterbury’s Human Interface Technology Lab (HITLabNZ).\(^8\)

As someone positioned in the field of information studies, I constantly wrestle with the complex relationship between information and knowledge. What makes information powerful? When does it support collaborative, narrative-focused learning? When does learning become a holistic act that requires the union of information and action? It is my sincere desire for the work presented in this thesis to be the start of a long dialogue

with others interested in similar questions. I am committed to helping broaden public understanding of how we use experimental and new media technologies in learning environments, and I hope that this work can contribute in a significant way to this end.
Chapter 2

AR State-of-the-Art

Because this research is about a bleeding edge technology\(^1\), and because the academic literature in this domain is both sparse and often dated by the time it is published, I believe there is a necessary rationale for including a brief, but by no means exhaustive, review of current development tools and projects that are relevant to this work. The following section documents some of the more prominent tools and frameworks available to the development community (current to summer, 2012).

At the commencement of this research, both Layar Vision and Qualcomm’s Vuforia framework were being introduced to the public and have, since then, helped initiate a fundamental shift in the expansion of vision-based AR. Studying their growth trajectories has given me an opportunity to elaborate on both the benefits and technical problems that are being experienced by developers and users as this technology becomes more familiar to the public. It should be noted that this review focuses primarily on mobile and tablet-based AR, rather than more immersive and embodied virtual or mixed reality, or untested developments like eyeglass-based, window-based, surface-based, and even holographic AR.

\(^1\)See Appendix B for a description of the term “bleeding edge,” which is used a number of times throughout this thesis.
2.1 Vision-Based AR Development Frameworks

This section is presented as a brief survey of select AR development frameworks, focusing on their capabilities, barriers to entry and cost, and the platforms they support. In order to better understand the nexus of critical factors motivating the growth of these projects, considerable time has been spent analyzing communication channels (like public wikis) used by the burgeoning development communities around these frameworks. There are a number of well-developed tools for location-based AR, from Layar, to Wikitude, to Mixare. Most are platform agnostic, but some, like Kudan, are available only on iOS. This is important only insofar as a significant portion of the AR development community has cut its teeth doing location-based AR which, despite using the same kind of technology and medium, is actually quite a bit different, and has significantly different uses. This survey isn’t meant to be totally exhaustive but, rather, a picture of the state of popular AR development frameworks available to the public at the time of writing.

  
  For a number of reasons, Qualcomm’s Vuforia framework, which has moved to the front of the pack among development kits for developing vision-based AR, seemed like a natural fit when I was faced with deciding which AR framework to use in experimental application building. It is free, cross platform, well-documented, and has a strong community of developers willing to share tips and information. Furthermore, the fact that it links with Unity 3D, the industry-leading 3D game development engine that offers a graphical interface as well as built-in scripting capabilities to enable things like animating 3D content, is its strongest selling point. For more information on my experience with Vuforia, see Appendix E.

- **Layar Vision:**
  
  
  When I first began this research, I was keen to explore the Dutch company Layar’s
Layar Vision platform. The support community was really mature, carrying over form Layar’s position as the most established locational AR framework, and the software was relatively easy to use (especially since I had already built a number of location-based layers using the Layar platform). I was worried about increasing cost, though, and it seems my worries were not unfounded. One of my interviewees, Ben, who is a Layar developer, comparing Junaio to Layar, commented that “Junaio is a lot more difficult system to work with. Layar kind of naturally fits into my toolset of programming, and I found all of the help materials and instructions and downloadable code really helpful. So the fact that they just had a great support site that was being recommended by a lot of people, that’s what made me adopt Layar. And to this point, I’d say I only stick to them because of loyalty. I’d have to say that Junaio apparently has a lot more in the way of capability.” Regarding the cost, he notes that “I haven’t tried the Layer player in other apps. Part of it is they’re attaching a lot of cost recovery to that.” Layar Vision costs €15 per reference image that is published in the publishing environment. Bundles of 100 pages can be purchased for €999. Test layers can still be created for free, but charges will be incurred once layers are published. Notably, location-based layers are still free to publish. I should point out that, of all my interview subjects who have experience developing augmented reality in some capacity or another, each one mentioned Layar specifically.

- Popcode: http://popcode.info/

Popcode has its own marker-based system and native client application that users download virtual content to. It is a Windows-only development environment, though, and is no longer actively being developed. At this point, it remains a potential testing tool, but cannot be used for publishing mobile AR content.

- ARmusk: http://armusk.org/
ARmsk is a free and open source, powerful, and extensible application program interface for markerless AR. It is for Android only, which can be seen as a limitation for any software trying to attract new users or developers when a significant portion of the user community owns an iOS device.

  Once a development standard, ARToolKit is not being actively developed anymore. I am only including it here because variations of it are still used frequently for experimental and research-oriented AR projects.

- **Satch**: [https://satch.jp/en/](https://satch.jp/en/)
  This looks to be the strongest competitor for Vuforia. Made by Total Immersion, a Japanese company, it is a free development and authoring environment, is platform agnostic, and has a player application that can be incorporated into mobile AR apps. While it does not have the market foothold that Vuforia does, it is mature, has a large development community (although much of the communication on forums is in Japanese), is supported by an established parent company that is responsible for the world’s most widely used commercial AR platform, D’Fusion, and looks very promising.

- **Moodstocks**: [http://www.moodstocks.com/](http://www.moodstocks.com/)
  Moodstocks is similar to Layar, and features both vision and marker-based AR via an easy-to-use web-based application programming interface. It is free for non-production use, but has a considerable monthly pricing structure dependent on number of image uploads (€299 for 1000 indexed images; €599 for 10,000 indexed images; €1599 for 100,000 indexed images).

- **Look!**: [http://www.lookar.net/](http://www.lookar.net/)
  Look! is Android-only, and is developed by a Spanish company with Spanish-only documentation. It is still in a very alpha stage.
• Metaio: http://www.metaio.com/

Like Vuforia, Metaio has Unity support, and also works with the Junaio browser. It is available for both iOS and Android, but is rather costly at ($325) for its AR “scene creator” tool.\(^2\)

• Junaio: http://www.junaio.com/

Junaio is free, and somewhat similar to Layar. Its Android app is not well-reviewed because of issues with some hardware platforms, although its iOS applications (for iPad and iPhone) are popular. It uses the Metaio Creator, an easy to use drag-and-drop application, for “gluing” 3D models to real-life images.

• buildAR: https://buildar.com/

buildAR is more of a content management system for AR, in that it allows end users to upload images. It has supported Layar Vision, although this appears to have ended as of August 1, 2012, and the creators are in the process of implementing support for Junaio. It is produced by HITLabNZ, a leader in augmented reality development, and features both free and “pro” (NZD$630) versions of its Windows-only development software, and a paid Mac version (NZD$245). (There is a 50% discount for students.)

• String: http://www.poweredbystring.com/

String is a popular, mature, fast, and flexible AR kit. It is iOS-only and, at the time of writing, has not been made available for Android. String, like some of the platforms mentioned above, features Unity 3D integration. It comes with a variable price tag, depending on available features and application deployment options, ranging from $0 to $7000 (per app, per year). While its iOS-only limitation is a hindrance for some developers, others, who develop exclusively on and for Apple

\(^2\)I should note that “costly” is relative here. While that may not seem much for a piece of software, many new developers will shy away from paid products, especially for getting their feet wet, when well-developed free ones (like Vuforia) are available.
devices, prefer it. It is discussed in further detail in the description of the Ultimate Dinosaurs exhibit at the Royal Ontario Museum.

2.2 Projects and Examples

The following are interesting examples of vision-based AR that illustrate the potential (and potential pitfalls) of this technology:

- BBC AR Jam was an interactive, AR-enabled storybook experiment undertaken by the BBC, who provided the story content, and HITLabNZ, which used the ARToolkit framework to provide the backend. This project is notable because it engaged a number of human-computer interaction researchers, as well as learning sciences researchers, in attempting to determine the viability of an (at the time - 2006) nascent technology in delivering interactive story content. I will describe a part of this project in greater detail in chapter 5. Smith et al. (2007) and Kerawalla et al. (2006) describe some of the project’s outcomes from a learning sciences perspective. Their findings suggest that: AR content must be flexible so that teachers can adapt it to the needs of individual children; AR systems need to deliver curriculum material in the same amount of time as more traditional teaching methods; children must be able to explore AR content; and AR development must take into account the nature and constraints of the institutional context into which it is to be introduced. This research, in many ways, set the stage for some of the AR-enabled textbooks that are popping up today.\(^3\)

- Letters Alive\(^4\) is a vision-based AR application designed around language acquisition and reading curriculum. Billed as “the first classroom curriculum based on

\(^3\)Such as the Japanese New Horizon series from Bandai/Namco, which can seen here: [http://www.tokyo-shoseki.co.jp/books/miraikkei/](http://www.tokyo-shoseki.co.jp/books/miraikkei/); or more science-learning focused content, like a solar system “magic book” developed by researchers at Eastern Kentucky University, described here: [http://www.arined.org/?p=666](http://www.arined.org/?p=666)

augmented reality,” it is part of an entire software and hardware package available from Logical Choice technologies that includes interactive digital storybooks and interactive whiteboards. Letters Alive provides a generic “learn to read” curriculum using AR-enabled flash cards that are scanned under an overhead camera and rendered on a nearby display screen, revealing animations based on the content of the cards. For example, an “L” card with a lion on it, when held under the scanner assembly, will present an animated, three-dimensional virtual lion on an adjacent display. In addition to letter cards, cards with complete words can be assembled into simple sentences. Included in the bundle, which costs $995, is a tracking mat that can hold 4 cards, the overhead scanner, a software suite, and a variety of cards and lesson plans. There are additional add-ons that increase the cost significantly. While the software appears mature from a design perspective, it has a dearth of content and, I would guess, will be used sparingly in many of the classrooms it ends up in.

- Ultimate Dinosaurs: Giants from Gondwana\(^5\) is a limited time, dinosaur-themed exhibit at the Royal Ontario Museum (ROM). Since before it even opened to the public, advertising has strongly played up the augmented reality component of the exhibit. Its homepage, email communications, and marketing displays throughout Toronto have boldly declared: “Not only will you see new dinosaurs in the exhibition, you’ll experience them in new ways through augmented reality (AR).”

The AR is experienced at individual viewing stations with mounted iPads positioned in front of full-scale dinosaur replicas. The iPads are fixed to articulated platforms with a limited range of motion that enable visitors to pan across the skeletal models in front of them, activating AR content that renders an animated virtual dinosaur over top of the skeleton. Animations include things like tails wagging and

\(^5\)Described here: [http://www.rom.on.ca/dinos/](http://www.rom.on.ca/dinos/)
jaws opening. The AR application is iOS-only due to the decision to use the String platform. In the frequently asked questions section on the exhibit’s website, they note the reliability of the iOS hardware platform (at the time of development), as well as the stability of the String framework, as motivations for creating an iOS-only application. That said, the iOS application is downloadable, and visitors are free to try it on their own Apple devices (iPads and iPhones), giving them far greater freedom and mobility, not to mention freeing them from having to stand in line to use one of the fixed devices. Since the exhibit commenced, a number of mid-sized tablet/mobile hybrid devices have come onto the market, including the iPad mini. I wonder how flexible the application and exhibit (and any off-shoots or re-uses of the code base) will be to the plethora of new device sizes and experiences in the coming months and years. Barry et al. (2012, p. 8) echo these concerns around a similar exhibit at the Natural History Museum in London, writing that “although tablets and personal devices have changed significantly in the three years since the original development, finding devices with the flexibility and robustness to be used by thousands within a public space is still a challenge and designing for the plethora of personal devices to ensure the experience is appropriately universal is equally so.” Li et al. (2012, p. 648) note AR’s potential for enriched interaction possibilities in museums, but they also point out that the pre-experience and after-experience of the visit are often not considered in these systems. The ROM seems to have taken this into account, to some degree, designing transit shelter advertisements throughout the city with marker-based AR built in that provides information about the exhibit, as well as realistic 3D dinosaur renderings. The mobile app, as a result, has a life outside of the exhibit which is worth noting.

For an exhibit that has so thoroughly publicized its use of AR, though, it doesn’t really feature a lot of AR, or particularly novel uses of the technology. The ROM isn’t a science centre, so the likelihood that they would consider designing some-
thing like this to incorporate more embodied types of interaction is probably fairly slim. Reliability is a key factor in a design such as this. This notion comes through in the mounted iPads, which resemble the sort of coin-operated viewers one finds at scenic tourist sites but, with their limited range of motion, ensure that visitors get a continuous, unobstructed AR experience when looking at a dinosaur through the device. To be fair, public AR experiences are still relatively new, so a delicate balance between immersive and spectacular on one hand, and accessible and meaningful on the other, has to be struck. While the virtual animations did little more than move a dinosaur’s tail, for example, there was no lag, and the mechanics of the animation were certainly “realistic” as far as mapping to what one expects a dinosaur’s tail would move like. There certainly weren’t things like hunt-and-chase scenes, virtual food chains, or evolutionary transitions, but there is always room to extend the exhibit to enable these more rich features once the initial phase is complete.

Styliani et al. (2009, p. 526) discuss the benefits of expanding digital media in educational museum settings, noting the potential to preserve and disseminate the cultural heritage information at a lower cost while, at the same time, promoting interaction and engagement to a wide spectrum of visitors. There is an emphasis on digital media throughout the exhibit, it should be noted, including incorporation of other new digital media technologies like gestural triggers (that activate digital information and animations when users walk by a screen outfitted with Microsoft Kinect sensors). While the exhibit is digital media-heavy, there are a number of material artifacts (fossils, casts), text-based information displays, and interactive activities for children that enhance the environment. While I was both jarred by the amount of digital media, but also somewhat underwhelmed by the AR after viewing the exhibit the first time, I recognize that something of this scale, with this much public attention drawn to both the exhibit and the technology, needs
to run without a hitch. Wyman et al. (2011, p. 465) caution about bringing digital media into spaces such as this: “use a little technology well, not a lot of technology poorly. Scale the content and experience to the technology and the environment.” I think this is sage advice for any reader interested in technology design in the environments at the heart of this thesis. The ROM is engaging in a number of initiatives to attract a younger audience at the moment, including a series of Friday night social events, which include alcohol and dancing, that are for adults only. I’d be curious to see a subsequent visitor study gauging the public’s reaction to the exhibit, especially new and younger members who identify as being drawn to the ROM by the broad marketing campaign around the use of AR in this exhibit.

- The Voices of Oakland project, an audio-only interactive history tour of the historic Oakland Cemetery in Atlanta, GA, the oldest in Atlanta, and an example of a Victorian garden cemetery, is notable for a few reasons. Its content describes both the history and architecture of the museum, through a narrative-based engagement, delivering audio stories about the various local historical figures who are interred there. It was conceived and implemented by researchers at Georgia Tech’s GVU Center (an academic leader in AR research) and has now been implemented on Argon, the world’s first standards-based, web-centric, AR web browser, from their Augmented Environments Lab. While this application is not altogether that different from past audio-based AR experiences in museums, but it enables the user to tailor the experience according to their own interests through an optional, hand-held interface. Through the Argon browser, visitors who are not present in the cemetery can select a panorama option that displays an immersive visual experience to accompany the customizable audio experience. This kind of multi-

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6Described here: [http://www.jdbolter.net/the-voices-of-oakland.html](http://www.jdbolter.net/the-voices-of-oakland.html)
sensory engagement, with a narrative focus as its foundation and a consideration for user customization, should be a model for future AR development in meaningful contexts.

- A few selected experimental projects are worth mentioning. Sony’s Magnat framework\(^7\), which uses a Playstation Vita’s camera to scan an environment in order to build a picture of where objects are located that it can then anchor virtual content to, is being presented as a tool that will enable users to, in the near future, augmented their immediate environments with virtual objects. It essentially creates a canvas for virtual augmentation out of one’s surroundings. Disney’s Revel\(^8\), which injects a weak electrical signal into a user’s body, creating an oscillating electrical field around them that can provide haptic feedback from objects the user interacts with, is being presented as a technology that will allow users to receive physical feedback from virtual objects, mediated by a screen-based device like a tablet, that a person is expected to perceive in front of them. Both of these experimental technologies have the potential to fundamentally change how AR can be made engaging for the general public, especially when one considers the diverse media interests of these companies (and possible marketing tie-ins that can go along with their introduction). Providing users with experiences that engage multiple senses, or can be mapped to environments rather than single objects, opens up the possibility for significant bleed between the material and virtual in environments where this kind of technology is incorporated.

While I am cautious about predicting any specific direction that the field may be going in, especially considering the fact that many of the more experimental and beta applications may never see the light of day, I am enthused about the number of freely

\(^7\)Described here: [http://mobilearexperiences.blogspot.ca/2012/03/sony-uk-presents-its-markerless.html](http://mobilearexperiences.blogspot.ca/2012/03/sony-uk-presents-its-markerless.html)

\(^8\)Described here: [http://www.disneyresearch.com/research/projects/hci_revel_drp.htm](http://www.disneyresearch.com/research/projects/hci_revel_drp.htm)
available AR development platforms. If this is ever going to be a commonplace technology, it will take the active participation of curious developers, and the easiest way to entice them is to provide accessible development kits, realistic use scenarios, and the potential to incorporate creative techniques (such as 3D animation) rather than simply relying on text-based AR annotation. As far as recommendations for best design practices in educational AR are concerned, I think the findings of BBC AR Jam are particularly interesting, especially the final one, that AR development must be sensitive to the institutional context in which it is introduced. I will elaborate on this throughout the following chapters, but it, as well as the possibility that more embodied, multisensory AR applications are currently shaping up to be a trend in the industry, are each significant.
Chapter 3

Literature Review

The study of information encompasses a multitude of theoretical and practical trajectories, including (but not limited to) library and information science, information science, informatics, philosophy of information, and museum studies. It is a shifting and multidisciplinary field.\footnote{See Buckland (1991); Saracevic (1992); Floridi (2011) for background.} Clearly defining the boundaries of each of these sub-domains is an almost a Sisyphean ordeal.\footnote{Furthermore, the overlaps between information and communications studies can be difficult to unfurl; Bates (1999) refers to the two disciplines as cousins, with the emphasis in communications studies placed on “the communication process and its effects on people” and the emphasis in information on the “process in service of information transfer.”} Recent dialogues have attempted to realign information behaviour - especially that which is associated with gathering, organization, storage, retrieval, and dissemination - along new axes, addressing its role in connecting the analog with the digital and, in the process, connecting it to its material underpinnings (Bates, 1999; Hayles, 1999; Buckland, 2012; Ibekwe-Sanjuan et al., 2010). Buckland (1991) notes the ambiguity of the term “information” in information science, distinguishing between information as process, knowledge, and thing. Despite trends toward reducing the study of information to simple concepts, many of which have to do with feedback or transfer, it is a live and dynamic field. Saracevic (1992) suggests that “information science is actively involved and implicated in the evolution of the information society.” Smith and Jenks
(2005) argue that “unlike ‘representationalism’ the idea that the world ‘provides’ information ‘to be processed’... auto-organization and informational imperatives are mutually attracted. Both are evolved, system or organism-specific phenomena.” My grounding of the readings reviewed here within an information perspective is a necessary condition for outlining an architecture to connect education, digital media studies, and a handful of other theoretical areas.

My research is grounded along three specific thematic and theoretical axes. The first, that the materiality of information and its study is critical to the questions this thesis addresses, and digital media that challenges traditional conceptions of information materiality (like augmented reality) should be analyzed through a materiality lens. The second, that critical information studies provides a reflexive and dynamic approach for understanding the changing information landscape of increasing digitization of media, as well as the relationship users have with information content. Finally, that constructivist pedagogy, and especially pedagogy that promotes collaborative and narrative-focused learning, is well-suited for educational digital media development in both formal and informal realms.

3.1 Digital Media, Augmented Reality, and Science Education

My thesis is concerned with the place digital media has in information, meaning-making, and, more specifically, science education. Recalling the introductory chapter of this thesis, it is my position that vision-based augmented reality (more so than location-based AR, which the general public is already more acclimated to) can be an effective tool in the arsenal of educators using digital media in both formal and informal science education.

Research dealing specifically with augmented reality goes back more than a decade in disciplines like computer science and electrical and computer engineering (Milgram and
Kishino, 1994; Starner et al., 1997; Shelton and Hedley, 2002). Only recently, has the study of AR as a medium gained traction in digital media and information studies, education, and museum studies, due partly to the availability of free (or inexpensive), easy-to-develop augmented reality frameworks, as well as the proliferation of mobile handsets that support the technology. Furthermore, the extensibility of AR as a medium means it is well-suited for areas linked to museum studies. Angelopoulou et al. (2012, p. 15) note that: “Current technology allows researchers and visual artists to investigate a variety of application possibilities using mobile-AR in domains not commonly associated with computer technologies (such as cultural heritage or performing arts).” While the literature in areas like electrical engineering and computer science, for example, often ignores some of the underlying philosophical questions around information behaviour, content creation, or meaning-making, I invoke readings from a number of often differentiated - and distanced - fields in an attempt to create a more holistic picture of augmented reality as a material, technological, and social phenomenon worth studying. But I also rely on works from engineering - particularly those that deal with human-computer interaction - to ground my study of the role digital media has in information as something both applied and tangible.

3.2 Materiality and Virtuality

The topics in this thesis are intertwined with the subject of the materiality of information in a number of ways. In “The Materiality of Informatics,” Hayles (1992) writes about the “complex articulations between embodiment and the body, inscription and incorporation, that are producing informatics even as they are being produced by it” in describing the impact that virtual reality was having in the early 1990s. This sentiment provokes a reconceptualization of the materiality of information, beyond simply materiality of information exemplified by text in books that can be picked up and smelled, or
artifacts that can be held in one’s hands. Hayles has had a crucial influence on my theoretical grounding, but she is certainly not the first to discuss information as a material phenomenon, nor has she been the only person to discuss the role that other readings of material culture - from anthropology, for example - have had on my understanding of what makes objects evocative. Miller’s introductory chapter to “Material Cultures: Why Some Things Matter” (Miller, 1998), especially the section on the materiality of different domains of objects that mean things to us, from semiotic markers to information technologies like radios, figures prominently, as does Ingold, especially as he writes about the relationship between knowledge and narrative: “knowledge lies in being able to place things within the narrative contexts of the relations through which they emerge (Ingold, 2010, p. 354).”

Milgram and Kishino (1994) were likely the first to define augmented reality as situated on a reality-virtuality continuum, between the so-called authentic world on one end and full-scale virtual reality on the other. Their seminal piece surveys the nascent stages of mixed reality development and, like Weiser (who I return to later), influenced a wide spectrum of researchers from a diverse array of disciplines, from Japanese computer engineers (Tamura et al., 2001) at the fore of technology design to education technology researchers (Hughes et al., 2005) to science and technology studies scholars (Star, 1999; Sassen, 2006).

Woolgar, a prominent figure in science and technology studies, moves this discussion into the social domain, as he attempts to create a set of maxims for wide societal uptake of virtual technologies in the opening chapter of his edited collection “Virtual Society?: Technology, Cyberbole, Reality” (Woolgar, 2002). Whether Woolgar’s postulate that virtual technologies should supplement rather than substitute for “real” activities still carries the same weight today that it did a decade ago is debatable, as more interactive virtual-enabled environments emerge and are able to provide new, and often different phenomenological approaches, to immersion which are not inauthentic or substitutive,
Figure 3.1: An updated representation of Milgram’s Virtuality Continuum.
but “real” in a different way. Frequently, virtual technologies rely on visual-perceptive information streams - especially technologies like AR that continue to require mediation through screen-based devices (for the time being, anyway). Will this continue to be the preferred approach as other sensory feedback systems (haptic, for example) that can interact with virtual content come to prominence? Haraway (1992, p. 324) writes that “in optics, the virtual image is formed by the apparent, but not actual, convergence of rays. The virtual seems to be the counterfeit of the real; the virtual has effects by seeming, not being.” In order for the virtual to become more “real” does it first need to activate multiple senses? Can augmented reality do this, or will it continue to be envisioned as mostly a visual and auditory medium?

Lev Manovich has long been concerned with the boundaries between art, communication, interaction, and new multimedia space, especially where information is interacted with wirelessly and, building upon the work of Weiser (1994), invisibly Manovich (2002, 2006). Manovich is not necessarily commenting about or making reference directly to augmented reality, but about spaces that facilitate a material-virtual blurriness. His primary thesis is that augmented space, which he defines as physical space overlaid with dynamically changing information, isn’t so much a technological interaction, but a cultural and aesthetic practice. Manovich highlights the fact that augmented space is monitored space. He suggests that information delivered to or extracted from augmented space is always accompanied by noise; it is never perfectly harmonious. At a more fundamental level, he wonders about the immaterial nature of new information flows within existing physical structures. Manovich dances between the worlds of information, visual studies, communications, architecture, and HCI, and his work ties as much to HCI theorists like Weiser as it does to information theorists like Star.

Dourish (2001, pp. 100-106) writes about embodiment being central to phenomenology, which given that phenomenology is not concerned with finding truths independent of our own experience but positions the phenomena of our experiences as central to on-
tological and epistemological probing and understanding, is a fundamentally interesting question to HCI researchers and designers. One of the key questions Manovich asks has to do with the phenomenological experience of being in a new augmented space. Is the information experienced within it personal? Mingers (2001, p. 124) calls for a phenomenological approach to understanding information systems, suggesting that they are intextricably involved in perception and cognition, and that their study has much to gain from recognizing that “human cognition and social action are inherently embodied.” Ultimately, Manovich (2006, p. 237) suggests that designers must start treating the invisible space of new media as something substantive. But he doesn’t focus merely on spatial questions. His anchor is the role that changing media practices has in arranging and bringing together groups of people. In The Language of New Media, Manovich describes a fundamental impulse of new media: that it remediates - that is it translates and refashions - other media, both in content and form (Manovich, 2002, 99-93). Manovich asks, toward the end of The Poetics of Augmented Space (2006), whether cultural institutions can play an active role as laboratories for testing alternative futures. This anchors my own research, as I am fundamentally asking whether institutions like museums can accommodate experimental testing of new media technologies, such as augmented reality.

Kirschenbaum’s (2004) ideas about the invisible characteristics - the material and philosophical inner workings - of databases also profoundly shapes the questions I ask and the nature of my methodological approach. What is the material substrate that information is inscribed upon? Where does it reside? How do we understand and abstract it? Kirschenbaum’s work has caused me to reflect on the sort of AR projects I want to engage in, and on ways this could be an interesting and engaging technology to develop for science and information learning, especially with regard to how this technology can be used to illuminate invisible processes and networks, beyond merely using it to annotate objects or their environments (a prevailing early focus of AR). Borrowing from Kirschenbaum, to understand an information technology, we must remove it from
the world of mere abstraction and stop reinforcing a perception of immateriality around it. For me, as a researcher designing augmented reality applications, this notion helps me imagine material and virtual interactions that, on the one hand, enable students to better understand the world around them and, on the other, probe questions at the heart of scientific enquiry.

3.3 Narrative and Storytelling

In October, 2011, I attended the TIFF\textsuperscript{3} NEXUS Locative Media Innovation Day, where the keynote speaker was human-computer interaction pioneer and Principal Researcher at Microsoft Research, Bill Buxton.\textsuperscript{4} Buxton gave a talk titled “Whereable Media: An Ecological Perspective” where he noted the importance of putting the narrative ahead of the technology when designing new media, stating “if you view things from a technological perspective, you will get it wrong.”\textsuperscript{5} Referencing a conversation he had with the film director, Norman Jewison, he noted that “it’s about story, or narrative.” Comparing the difference between the engagements with technology of yesteryear - over the phone, or in front of a television set - to what might be found today, with pervasive computing and media technology, Buxton noted that the computing more than ever needs to be designed in support of its capacity to foster narrative. He implored designers to tell good stories with their designs and applications in order to compel users to return to them once the sheen has worn off the device.

Jerome Bruner, an influential education theorist and pioneer in constructivist education, has been promoting a narrative-driven or narrative-centred learning model since the 1980s. In “The Narrative Construction of Reality,” he suggests that we organize

\textsuperscript{3}Toronto International Film Festival

\textsuperscript{4}Buxton is a lifetime achievement award recipient, the most prestigious award given by the Association for Computing Manichery’s Special Interest Group on Computer Human Interaction, which is the foremost organization in the field of HCI. Only 17 others have every been bestowed with this honour, including luminaries like Terry Winograd and Lucy Suchman.

\textsuperscript{5}A recording of Buxton’s keynote can be found at \url{http://www.youtube.com/watch?v=e0Jqs9IcTJY}
our experience and our memory of human happenings mainly in the form of narrative: stories, excuses, myths, and reasons for doing and not doing (Bruner, 1991). Unlike logic or scientifically-driven dialogues, conventional personal narratives become a version of reality whose acceptability is governed by convention and communicative necessity “rather than by empirical verification and logical requiredness.” Bruner goes to great lengths to describe the differences between the internal narrative mode of thought, and narrative discourses between people. He is careful, however, to point out that a narrative is simply an account of events happening over time that can include future events. Importantly, narratives have to be accountable to the intentional states of those who generate them - their beliefs, their desires. Successful narrative events do not always have to refer to reality, but should be accessible and normative, and, most importantly, context-sensitive. In order to fully realize effective narrative engagement, the symbolic systems of culture must be enabled. While Bruner describes how we think we construct reality according to narrative principles, he does so firmly alongside other foundational constructivist works by the likes of Piaget (1929) and Vygotskii (1978). When Bruner wrote “The Narrative Construction of Reality,” he was already a paramount figure in constructivist education, and was widely recognized as the father of scaffolding, a theory within education research that I return to in the Future Work chapter of this thesis.

Bruner (1986, pp. 11-44) writes of two modalities of cognitive functioning, or two modes of knowing: a paradigmatic or logico-scientific mode that attempts to fulfil a mathematical system of description and explanation; and a narrative mode that leads to good stories, gripping dramas, and deals with the vicissitudes of human intentions. It is the second that I am most occupied with. Stories, to Bruner, “occupy a landscape of action” made up of agents, intentions, goals, situations, and instruments, as well as a “landscape of consciousness” that includes what those involved in the story know, think, and feel. Believability is a fundamental concern. Because achieving realistic, believable stories and curriculum modules is, and should be, a foremost concern for those researching
cognition and learning, careful attention must be paid to the roles that narrative and storytelling have in designing and developing digital media for education. As Riessman (1993, p. 3) notes, “nature and the world do not tell stories, individuals do. Interpretation is inevitable because narratives are representations.” Invoking Bruner, she suggests that narratives aren’t mere information storage - they structure perceptual experience and help organize memory. While narrative is a multi-faceted subject, especially in the context of constructivist education, it is linked to a number of themes that recur in this research: scripting; scaffolding; the accounts of protagonists; and user agency. I question how these themes might be accounted for and bridged in new media and educational technology design. Designing educational media with narrative considerations in mind is not a new theme, though. Laurillard et al. (2000) note that “narrative is fundamentally linked to cognition and so is particularly relevant to the design of multimedia for learning.”

Juul (2005, pp. 16-17) makes a distinction between narratology, originating from Aristotle and the study of storytelling media, and narrative, which is thought of today in a much broader sense. He notes a narrative turn, after which, he suggests, “it has become common to see narrative as the primary way in which we make sense of and structure the world.” To Juul, whose primary work is in the field of game studies, things like scientific discourse, or our understanding of our personal lives, are structured using narratives.

In “The Myth of Superman,” Eco touches on a host of related themes (Eco and Chilton, 1972). Examining Superman (in serial form), Eco unpacks a character that most readers can identify with. A central character, he argues, must be an archetype, the totality of certain collective aspirations, replicating the permanence of identity built within public discourse. Superman is the result of a narrative plot that multiplies through an indefinite series of public encounters. Eco pontificates a little on the philosophy of temporality, emphasizing that before causally determines after, noting that the plot must not consume itself, even where there is little wariness of a conventional plot. Eco
Chapter 3. Literature Review

highlights the fact that Superman’s popularity is primarily situated on a bedrock of civic consciousness and responsibility completely separated from political consciousness. He represents a semi-homogenous totality, where what is “good” goes without question. Many of the more game-like AR applications that are emerging, especially those focused around serious or public education themes (environmental issues, for example), can be described in this manner.  

Manovich (2002) makes a case for thinking in terms of cultural interfaces:

As distribution of all forms of culture becomes computer-based, we are increasingly “interfacing” to predominantly cultural data: texts, photographs, films, music, virtual environments. In short, we are no longer interfacing to a computer but to culture encoded in digital form. I will use the term “cultural interfaces” to describe human-computer-culture interface: the ways in which computers present and allows us to interact with cultural data.

“The Myth of Superman” establishes that the media we create to engage the public must be situated within a cultural continuum. 20th century North American society was prepared to accept Superman. What tropes and archetypes will 21st century learners be prepared to accept? There are, of course, counter-examples. The public does love villains and counter-culture heroes, so does this necessarily mean that the archetypes used in AR and digital media narratives must also be situated in a similar cultural continuum? The second suggestion is that effective design which attempts to engage a relatively homogenous group needs to be serial and iterative. It needs to slowly release new content that is generated only after the initial group temperature can be measured. Modular components, released in an orderly and predictable fashion, can really extend the lifespan of a good application, and new media designers should be aware that this is as true now as it was with the media of the 20th century. The power of narrative to

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6See Liarokapis and De Freitas (2010) and Anderson et al. (2009) for case studies of AR-based serious games.
drive media design in an educational context cannot be underestimated.

### 3.4 Bringing Together the Formal and Informal

In the April, 2010, “Special Issue on Science” of *Curator: The Museum Journal*, Dribin and Rickhoff (2010, pp. 221-227) suggest that digital environments are among the least fleshed-out components in the chapter on media in the influential “Learning Science in Informal Environments” report that was published a year prior (Bell, 2009). Their most important recommendation is for museums to “both become familiar with the breadth of research that is available related to digital environments” and “continue to specifically build an understanding of how this works in a museum setting.” They go on to add that museum staff “should thoughtfully look at available design techniques and tools that tie evaluation of the environment directly to the learning outcomes.” Bell (2009, p. 267) does briefly address a problem with introducing AR and VR in designed settings like science centres - that it is a challenge to determine whether people visiting exhibits in a group will have the same experience with the virtual technology. A great deal of the research on digital environments in the learning sciences that Dribin and Rickhoff are referring to is screen-based, and not necessarily mobile, but that doesn’t mean museums cannot draw from this literature to determine some recommended design practices.

With that in mind, there are projects that attempt to strengthen connections between collaborative, technology-enhanced learning in museums and classrooms. Cahill et al. (2011) describe their development of the Zydeco system, a mobile application and online platform in support of what they call “nomadic project-based inquiry between the classroom and out-of-school settings such as museums, zoos, parks, and aquaria.” A recent demonstration of the application by two of the members of the development team that I attended showed a promising amount of care toward enabling students and teachers to collaboratively plan an investigation through the application, and then sort
and analyze evidence in order to make scientific explanations to complete their investigations. The scenario that they described involved the planning phase taking place in a classroom, and the investigation taking place on a field trip to a science museum.

The influential social anthropologist and learning theorist, Jean Lave, writes that “formal education was supposed to involve ‘out-of-context’ learning in which instruction is the organizational source of learning activities” where “learners build understanding through abstraction and generalization,” while “informal education learning was supposed to be embedded in everyday activities” with the product being literal, context-bound, and not conducive to general transfer (Lave, 1996, p. 151). She has argued against this comparative model of education, suggesting that learning transfer is extraordinarily narrow account of how learning happens in interrelated settings. She writes that “distinctions between the rational knowledge content attributed to school ‘curriculum’ and the broad moral (but simultaneously narrow skill) focus assumed for ‘informal education’ ignore the skills and moral content of schooling and the knowledgeability that is part of all educational practices.” She further argues that teaching is not a precondition for learning, and that the absence of teaching shouldn’t call into question processes of learning. With the absence of a teacher, or the teacher taking on the role of a docent in a science centre, can the transfer of learning take place in a more collaborative, peer-based way?

Multi-institution, long-term initiatives like the LIFE Center (Learning in Informal and Formal Environments) continue to produce a veritable treasure trove of research on the connections between informal and formal learning, including insightful work on the neurobiological and cognitive foundations that underpin each, such as Bransford et al. (2005a,b), and detailed studies of more contextual and factors, such as in Bell (2009) which was mentioned above, and Banks (2007), which focuses more on sociocultural factors.

That said, some of the most important work in this area is around bringing together diverse groups of stakeholders to develop effective collaborative design processes that
benefit those on all sides of the spectrum. Hoadley and Cox (2005) describe such a process as part of a course on learning design methods. Their work emphasized learning design as something that encompasses interaction design and requiring “an enormous wealth of strategies and empathies, ranging from understanding interaction design goals such as usability, engagement, or interactivity, to understanding particular audiences, to understanding a content domain plus its attendant pedagogical content knowledge, to understanding general principles of learning.” Such a holistic and thoughtful model for teaching educational technology design in a reflexive way to designers, programmers, and content creators across the informal and formal spectrum is critical if we are to imagine building applications and experiences that move beyond the novel, trivial, and spectacular toward the meaningful, collaborative, and evocative.

3.5 Critical Information Design

Vaidhyanathan (2006, p. 293) notes that critical information studies takes, as part of its focus, an approach to studying “the rights and abilities of users (or consumers or citizens) to alter the means and techniques through which cultural texts and information are rendered, displayed, and distributed.” Ratto’s (2011) notion of “critical making,” falling within the scope of critical information studies, informs my approach to designing and creating collaborative learning engagements. In every case, and certainly in the application described in Appendix E, I value two things: approaching the design through a critical framework; and enabling the end-users to have a voice in the product that is designed. This notion of enabling the voice of end-users (in this case, students and other learners) is influenced by the concept of emerging learning objects (ELO) that forms the bedrock of the Science Created by You (SCY) project (De Jong et al., 2010). The SCY project offers students a learning experience that is based on real life, challenging, and focused on inquiry and collaboration. Learning is seen as a process of creation,
where ELOs are produced. ELOs are created by students, with the entire pedagogical approach in SCY based around the premise that learning is seen as producing ELOs. They are meant to be collaborative and iterative. Examples include concept maps, data sets, tables, and reports.

The base of information studies is dispersed over a number of sub-disciplines, none of which are necessarily “critical.” Critical information studies (and my research in general) is interested in interrogating the structures, functions, habits, norms, and practices that guide global flows of information and cultural elements. It asks questions about access, costs, and chilling effects on, within, and among audiences, citizens, emerging cultural creators, Indigenous cultural groups, teachers, and students, and is interested in promoting the ability of citizens to use signs and symbols ubiquitous in their environments in manners that they determine (Vaidhyanathan, 2006, p. 303). For the most part, this research interacts with the areas of information that deal with computation, semiotics, and meaning. From a technical standpoint, this includes knowledge media design, human-computer interaction (especially embodied interaction), media theory, and cognitive science. From a theoretical standpoint, it is profoundly influenced by constructivist pedagogy. This research touches on a few direct themes that are relevant to contemporary information studies. Notably, these are: the materiality of information objects; transformative information practices in education; and the visualization of information architectures and infrastructures. None of these sub-disciplines is necessarily “critical” though, and this research is interested in promoting what Ratto (2011) characterizes as a crucial component of a critical making approach: the role of investment in connecting lived experience to critical perspectives.
3.6 Reconfiguring the Interface

Finally, I want to focus on some of the human-computer interaction literature that has been crucial to this research. Weiser’s (1994) “The World is not a Desktop” is a seminal pre-internet piece that fully introduced the concept of seamless interfaces, and invisible, backgrounded computing tools. Weiser was a chief scientist at Xerox PARC, and is widely considered the father of ubiquitous computing (ubicomp).\footnote{He unfortunately died of cancer in 1999, well before he could see how prescient his writing would become. Harrison et al. (2010) comments on Weiser’s prescience. Dillenbourg et al. (2008, p. 101), Dourish (2001, chap. 2), Greenberg et al. (2011), Harrison et al. (2010), and Ma et al. (2005) all comment extensively on his legacy.} Weiser laments that the metaphors for computing (the time of writing would have been mid-1993) lead us away from the invisible tool and toward placing the tool (or device) at the centre of attention. He suggests that research on agents, speech recognition - all focal points at Xerox PARC at the time - are not interesting or important because they are in the domain of the conscious interaction. Interfaces need to be everywhere, but not highlighted and, ideally, not even apparent. Weiser suggests that computing devices should be like our childhood - a foundation that is quickly forgotten, but always with us, seamlessly embedded into the fabric of our daily lives. Weiser wrote this at a time when ubiquitous computing was but a germ of an idea. There was no such thing as wireless smartphones, or embedded sensors invisibly communicating data about groups or individual users. Despite the brevity of this 2-page introduction to interactions (one of the Association for Computing Machinery’s flagship journals) its importance can hardly be measured.

Greenberg et al. (2011) continue from Weiser, but with a modern twist borrowed from the anthropologist Edward Hall. Hall (1969) first coined the theory of proxemics, which has to do with the culturally-dependent ways that people use interpersonal distance to mediate their interactions with other people. What Greenberg and his colleagues have done, first, is to operationalize (or to make measureable for developers) proximity. They do this by measuring distance between bodies, orientation, identity, movement, and
location. For them, ubicomp proxemics concerns inter-entity distance, where entities can be people, devices, and analog objects. Greenberg and his team’s foremost concern is to focus on understanding interactions between people before they can go about building technologies that might enhance those interactions. They invoke Buxton, reminding us that it is not the technology that counts, but the interaction and the context that we should focus on as researchers. These are the kinds of interactions I want to design, build, and study. These are the kinds of interactions that enable us to create designs and applications that foster rich dialogues with one another and compel users to return to them once the sheen has worn off the device.

Suchman (2007) suggests that it is not conversation at the interface that we need to address, but creative assemblages that explore the particular dynamic capacities that digital media afford. Her classic text “Plans and Situated Actions,” which she wrote while doing ethnographic research as an anthropologist and philosopher (and student of Hubert Dreyfus) on artificial intelligence work at Xerox PARC in the 1980s, has recently been updated and extended (Suchman, 1987, 2007). The updated version, titled “Human-Machine Reconfigurations,” includes a section called Inhabiting the Interface that begins by invoking the Danish computer scientist, Susanne Bødker⁸, to discuss the shift from interface as an object to a connective medium. She questions the nature of interfaces as the content it delivers becomes less a substitute for a material thing and more a site with its own specific materialities and possibilities. This question around what the nature of an interface is, as the content it delivers becomes less a substitute for a material thing and the interface becomes a site with its own specific materialities and possibilities, is crucial. Suchman discusses an interactive installation that provides a space characterized by predictability and contingency (which, on her theoretical ground, stands for context-dependence).

Fundamentally, Suchman is asking what it means to be human within the zone of

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⁸(Bødker, 1991)
interface reconfiguration. What I am engaged with, is *what does it mean to be a learner within the zone of interface reconfiguration*. She points out that the human she describes isn’t an autonomous, rational actor, but a shifting biography of culturally and materially specific experiences. To reiterate, what is simmering up to the surface of her writing is that context is everything. Encounters with new media technologies don’t change the human so much as they provide new contexts within which to frame possible future encounters. Wesch (2009), writing about changes in university education (but in a way that is applicable here as well), suggests that “it is this ‘spirit’ of Web 2.0 [interactivity, collaboration, and participation] which is important to education. The technology is secondary. This is a social revolution, not a technological one, and its most revolutionary aspect may be the ways in which it empowers us to rethink education and the teacher-student relationship in an almost limitless variety of ways.”

The original edition of Suchman’s book, which provided some of the theoretical underpinnings for the field of human-computer interaction, has long been a fixture in curricula as diverse as artificial intelligence, cognitive science, anthropology, and information studies. Her fundamental points about interface design remain unchanged between the two editions of this work. She is concerned with design and interaction, to be sure, but she is also a philosopher who weighs the unseen currents associated with new technology experimentation and adoption. She reminds us that we don’t build for specific actors; we build for contexts. We learn from contexts, not from the interactions of specific actors. I have found direct application of her theories in the area of inclusive design, where it has been challenging to imagine an application that can have a life outside of the one-off context for which it is built, and be accessible to many different users. While I recognize that it isn’t always possible to design interactions for every user, it is worth abstracting away from the specific use case when trying to assess positives and negatives, as well as to focus on variables specific to the interaction under consideration.
Chapter 4

Methodology

The research outlined in this thesis is qualitative, the bedrock of which is a set of twelve hour-long interviews with highly-experienced educators, developers, researchers, and designers, which have been designed and analyzed using a grounded theory approach. These interviews have been enhanced by a short case study of my experience with the design and development of an educational vision-based AR application for a local school (which is described in Chapter 6). This research is fundamentally about two things: the viability of vision-based augmented reality as a tool for creating rich and innovative pedagogy for classrooms and science museums; and connecting developers, educators, and other designers in the formal and informal science education fields who are working with these sorts of digital media tools.

4.1 Data Collection

As noted, the primary means of qualitative data collection was a series of interviews conducted with experts in educational and technology fields from both the formal and informal worlds. This included teachers with experience bringing digital media into their classrooms, developers who build educational technologies, researchers from both museology and education, and administrators. The interviews were semi-structured and
focused on themes that crossed disciplines, but were also open-ended and personal enough to engage in lively discussion about an interview subject’s specific area and experiences, enabling them to offer unique perspectives on how digital media influences learning and how different stakeholders might make the most of the opportunities at hand. The interviews were done over a 3-month period. This afforded the possibility for reflection and strategic adaptation as new discoveries were made about, for example, the different languages that developers and educators speak, or the centrality of subjects like user-generated content to people from the informal education sphere. Roughly half of my interviews were with people I had had previous contact with - mostly through short conversations about their work. This facilitated a more conversational tone that, in the end, I feel had a strong impact on their willingness to engage in really meaningful dialogue.

4.2 Participant Selection

Initially, my intention was to start with a large focus group made up of members of the different stakeholder groups. The motivation for this had mostly to do with wanting to collect data from a large sample population that could be generalizable. More than anything, though, I wanted to communicate with the very best AR developers releasing applications at the time of research. After attending a few AR-related events, however, I realized that many of the developers I came across had little-to-no training in educational sciences. Recognizing that my study would be about the educational value of this technology, and not about its use in marketing, games, or instructional content, I soon re-evaluated the merit of doing a broad study versus a narrow one concentrating on people whose experience spanned education and new media technology deployment.

Furthermore, because this tends to be a field that frequently sees sudden and potentially game-changing technological shifts, I wanted to collect the insights of individuals
who have firmly cemented themselves as experts in their particular field, across a range of disciplines and contexts, who would be able to comment not only on the current state of the technology or pedagogy, but also on how it has changed, and how their practices have changed to accommodate these technological shifts. That said, I also sought a diverse range of opinions, including those of people with only cursory knowledge of vision-based AR specifically. For this reason, interviews were conducted with a small, select group of experts from the following fields: learning sciences, educational technology development, museum research, museum administration and curation, interaction design, digital media development, and formal science education.

I deliberately sought to interview experts across different sectors. I was interested in a variety of experiences and opinions that cross disciplines and backgrounds, and felt that contacting potential interview subjects from a broad spectrum of areas, and using a non-pedantic approach, while not necessarily as statistically sound or representative of a specific population, would produce more interesting and useful data in the long run. Of the nearly thirty potential interview subjects I contacted, each of them falls primarily into one of the following groups: developer or designer; educational technology researcher; museum administrator; museum researcher; school teacher. In nearly every case, the interview subject fell into more than one of those categories, frequently blurring the lines between researcher and developer or creator. Of the developers and designers group, I sought those who have experience working with digital media and, especially, some form of virtual reality. The educational technology researchers I solicited almost exclusively came from areas of research that focus on interactive technologies, rather than simply browser-based or laptop-based work. The museum administrators I contacted came from North American science museums. Most of the museum researchers I contacted focus on cultural and historical museums as well, but in most cases their primary research deals with science museums. Finally, of the group of school teachers I contacted, every one is a Canadian elementary or secondary teacher who teaches some
Table 4.1: Number of potential interview participants contacted, identified by primary and secondary occupations.

form of science education and has had a digital media intervention in their class. Of the 12 interview subjects, they are currently spread across 4 countries, and while I didn’t ask about their personal backgrounds, I know that at least 4 are immigrants in the countries where they currently reside. 10 speak English as a first language, while two speak it as a second language. See Table 4.1 for the specific breakdown of professional background of the potential participants who were contacted.

The pool of interview subjects was chosen taking into account their experience and familiarity with the technology. Quite often, there is a technological and experiential requirement to understand AR technology. While further research might benefit from soliciting broad public opinion, my desire was to benefit from the expertise of people deeply familiar with the kinds of issues I sought to engage with. Thus, a list of potential interviewees was created, influenced by the following variables:

- The subject straddles the fence between developer and researcher;
- They have an understanding of both the formal and informal education worlds;
- They have a long track record of research or development experience in one of the areas studied here;
• They’ve introduced an interesting perspective in their work (related to this research) that I am interested in exploring further.

4.3 Participant Descriptions

4.3.1 Educational Technology Researchers

• **Ueli** is an academic researcher and head of a development lab at a university in Europe. His academic work focuses on educational technology across formal and informal learning, and he is the primary investigator behind a current project exploring mixed reality in educational contexts. Ueli expressed his preference for working in museums to me during our interview.

• **Tim** is a computer scientist and educational technologist at a North American university. His work is at the intersection of human-computer interaction and educational technology and his research focus is on the design of interactive technologies to support education. He has a long history of developing virtual media for classroom engagements.

• **Ella** is an education sciences researcher at a university in Europe. She focuses on collaborative development and design practices, as well as novel human-computer interactions in classroom environments.

4.3.2 Museum Researchers

• **Pam** is a museum and educational technology researcher at a university in Europe. She has a background in learning sciences, and her current research focuses primarily in museums. She has participated in a number of research projects that explored the introduction of mobile and social media technologies in museums.
Donald is a researcher in the fields of museum education and science education at a North American university. He has done extensive research into topics as wide-ranging (but relevant to this thesis) as science learning in informal environments to school field trip visits to science centres.

4.3.3 Museum Administrators

- Henry is an executive at a North American science centre. Prior to taking on this position, he obtained a PhD and worked as a biologist, but his knowledge spans a breadth of subjects, from languages to philosophy.

- Charlotte is a staff scientist responsible for education initiatives at a North American science centre, where she has worked for the past few decades. She also teaches university courses in science communication, and is nearing completion of a PhD in a related field.

4.3.4 School Teachers

- Maya has a PhD in a biology-related field, but has worked for a number of years as a biology teacher at an exclusive private secondary school in a North American city. She originally hails from Latin America. She has participated in the collaborative design of a successful, multi-year digital media engagement for her classroom.

- Jocelyne is a primary teacher at a North American private school where she teaches, among other things, biology. She has also participated in collaborative design of digital media engagements for her classroom (it should be noted that she does not work at the same school as Maya).
4.3.5 Developers and Designers

- **Nathan** is a content programmer for kids gaming and new media initiatives with a major cultural institution in a North American city, where he has worked in family and youth education programming and researched topics like digital literacy and storytelling. He is currently part of a team designing a large public augmented reality project.

- **Mike** is a developer of digital media content and founder of an interaction design company that has recently installed major exhibits in prominent museums and science centres around the world.

- **Ben** is an augmented reality developer, former teacher, and faculty member in a biomedical communications department at a North American university. He has a long-standing involvement in science education.

4.4 Interview Method

All of the interviews were conducted in the spring and summer of 2012. All of the recording was audio only, although extensive notes about the interview context - e.g.: time of day, day of week, setting - were taken. See Table 4.2 for a breakdown of the modes of interviewing employed. Because of the small sample, loose demographic data was collected - approximate age; presented gender; native language - only where it might shed further insight into the kind of responses the subject would give. As a result of my desire to enable more free-flowing conversation, I did not adhere strictly to a specific script of questions uniformly across every interview, wanting instead to allow the interview participants to express themselves in as unencumbered manner as possible. This was done in line with a grounded theory approach, as I felt that it would enable
<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
</tr>
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<tbody>
<tr>
<td>In Person</td>
<td>4</td>
</tr>
<tr>
<td>Skype (Voice)</td>
<td>4</td>
</tr>
<tr>
<td>Skype (Video)</td>
<td>1</td>
</tr>
<tr>
<td>Phone</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4.2: Mode of Interviewing

more valuable free-flowing, conversational interviews\(^1\). While there is surely value to be derived from asking tightly-scripted interview questions, a sample of this size - one that focuses on qualitative rather than quantitative metrics - benefited from more open-ended, probing questions that relied on shared interests between interviewer and subject. Furthermore, because I am interested in a variety of experiences and opinions across a broad spectrum of subjects, narrow questions that don’t transfer across fields were avoided.\(^2\)

The primary aim of this kind of focused data collection has been to collect insights, critiques, and suggestions for how an effective material-virtual paradigm shift might enhance educational environment design. As such, the search for emergent themes was a continuous activity throughout the interview process. For example, if a developer, or an interviewee with advanced technical expertise, expressed reservation about the viability of wearable-based AR in the immediate future, this would influence the sorts of questions I’d ask content creators and educators. Another example would be if curators and museum theorists expressed reservation about the increasing introduction of mobile devices in museum environments, I would then attempt to find out whether developers shared similar reservations (without prejudicing the interview).

\(^1\)See (Berg and Lune, 2004), especially chapter 4, titled “A Dramaturgical Look at Interviewing.”
\(^2\)See Appendix C for a list of interview questions that were used to guide the process.
4.4.1 Communication and Recording Procedure

Because many of the respondents are not based in Toronto, a number of the interviews were conducted over Skype or on the phone. I was not looking to measure quantifiable biometric cues or signals in their responses, so I didn’t consider face-to-face (or some other visual communication stream) to be necessary for that purpose. Each interview lasted for between 45 and 90 minutes, with the average interview lasting approximately 50 minutes.

All interviews were transcribed verbatim using an open source software package called Transcriber AG\(^3\), which enabled me to create notes about the participant, as well as label sections and keywords, throughout the entire process. While I endeavoured to acknowledge every nuance and inflection, I recognize that interview transcription in qualitative research can be interpreted as a constructive activity in which the transcriber is selective about what to include and what not to include in the analyzed data, and that there is an unavoidable use of cultural skills by the transcriber in interpreting the data (Creswell and Miller, 2000). That said, my aim was to convey what was said, how it was said, and with any emphasis necessary.

4.5 Ethical Considerations

This research was undertaken with the utmost consideration for the privacy of the interview participants, and was conducted under the auspices of the University of Toronto’s Social Sciences, Humanities and Education Research Ethics Board. A decision was made early on to anonymize all participant data and use synonyms throughout this thesis.\(^4\)

While I felt that it was beneficial to conduct interviews where participants were assured of their anonymity as it allowed them to be rather candid and, in many cases,

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\(^3\)http://transag.sourceforge.net/

\(^4\)A copy of the consent form signed by participants is included as Appendix F.
offer opinions that they might not have were they required to attach their names to them, it had the negative consequence of preventing comparison between interview data and the published work of participants, most of whom have solid publishing histories.
Chapter 5

Analysis of Interview Data

The following chapter analyzes the interviews conducted as part of this research. As outlined in the previous chapter, I strategically interviewed people with considerable experience in order to move beyond simple questions about engagement with specific media or technologies and toward discussion about relevant past and present research, leaving plenty of space for well-formed opinions and predictions. This chapter addresses the positions outlined in my introductory chapter and literature review, and then expounds on unanticipated and emergent themes from the interviews. I am operating from a foundational principle that understanding the people interacting with these environments is as important as understanding the technology. For this reason, the weave of qualitative techniques I employ triangulates data from experts in a variety of informal and formal education areas alongside my own experience using the same development tools many of them use. Furthermore, part of my commentary and reflection is devoted to critically analyzing my role in this research, as well as the roles of those responsible for pedagogical decisions who I interact with along the way. This forces me to be accountable for all aspects of my research process, and not simply the data collection or analysis, as I question some of the underlying principles about how this sort of development work happens in learning environments.
5.1 Grounded Theory

My procedure for analyzing data had, at its foundation, a grounded theory approach. Grounded theory is a research method that, rather than beginning from a hypothesis, suggests that research should start with the collection of data, which is then coded according to relevant points emerging in the interview transcripts. At its most basic foundation, grounded theory is a method of comparative analysis. In grounded theory research, there are different approaches a researcher can take with regard to taping or not taping interviews, avoiding pre-interview theoretical analysis (in order to ostensibly refrain from clouding one’s perception of possible outcomes), or talking about theory with participants (Glaser and Strauss, 1967; Glaser, 1978, 1992). I adopted a Straussian approach to grounded theory analysis, which is more flexible with regard to connecting findings to theory, theoretical sampling (and subsequent adaptation according to the state of findings), and constant comparison (Strauss and Corbin, 1994; Corbin and Strauss, 2008). In this case, I started with an open coding scheme that was slowly refined. Through a reflexive strategy that involves constant comparison between transcripts, codes are then grouped into a conceptual layer, and then concepts can be further grouped into categories from which theoretical explanations will emerge that help explain the research.

A strong reflexivity has guided this analysis. Consideration was given to critical factors such as: the number of and type of respondents who replied to queries for interviews; the time required to adequately process data; and wariness of coding in a silo. The group of interview subjects are not intended to be a representative population sample from which general statistical claims can be made. Rather, their interviews provide in-depth and knowledgeable insights to the myriad questions brought up in this research. Employing grounded theory in the research design, as well as the analysis, has enabled me to be far less passive as a researcher, allowing my own developing insights to adjust the direction of later interviews as prominent themes began to emerge, to provoke and open up new and interesting lines of inquisition, or to change the sequence of analytical events
(Charmaz, 2006). At the analytical level, grounded theory has enabled me to develop a robust and reflexive process for grouping important sections thematically through a constant comparative method between theoretical lines and phenomena as they appear in the coding process. Glaser and Strauss (1967) offer the most thorough outline of these principles, including making decisions about data collection based on initial sampling and initiating the coding process while collecting data in order to adapt it based on emerging theoretical concepts.

One of my reasons for employing a grounded theory methodology had to do with wanting to let the data really speak for itself. I felt that, by letting people with vast experience and knowledge in the area I am exploring have ample space to discuss their thoughts, I would be able to interpret their interview data in such a way that it could stand on its own, without necessarily relying on my translation or interpretation to prove meaningful. This element of grounded theory methodology isn’t without criticism, though. Allan (2003) questions the grounded theory maxim that interviewers should have no preconceived notions, suggesting that “there has to be some agenda for research by interview” or interviewees will see it as a waste of time. A further critique of his, that I somewhat agree with (but also see as a potential benefit to future research), is the notion that grounded theory doesn’t define a clear ending to the collection and analysis stages. Rather, it recommends letting findings emerge and continuously assessing when and how the data collection and analysis processes should flow into each other.

5.1.1 Coding Scheme

In the initial coding stages, the following consideration was paramount: context is crucial, and highlighted terms and categories should reflect this. I was interested in the frequency of terms, to be sure, as well as the enthusiasm shown by participants toward particular theoretical or technical subjects, but I was especially interested in their description of contexts. I did an initial round of coding by hand, using an open coding scheme. Because
I was coding on my own, the initial terms I selected were based on the vocabulary used by interviewees (and the vocabulary that represents the contexts they were describing).

Upon culmination of hand coding, I began a second, more concentrated coding process using a qualitative analysis software application for the R programming language called RQDA.\(^1\) Aside from featuring a set of robust qualitative analysis tools in the software’s user interface, as well as more quantitative-focused statistical analysis tools (via features of the R language), RQDA stores the interview data in a SQLite database that can also be queried. In this second stage, I re-coded in a similar manner to the earlier hand-coding process. Once complete, I read over each interview transcript again and began to loosely structure codes into a conceptual layer that was organized, at first, according to the frequency with which codes recurred, and then according to whether or not the code was mentioned by participants from different fields. From this comparative process, where recurring codes were grouped according to their number of occurrences, and then according to the number of participants who mentioned them, the predominant themes of the analysis began to emerge. Furthermore, because I sought to ground interview data in existing literature I had encountered, coded passages that spoke to relevant research, or that fell into a particular theoretical frame, were noted.

This more concentrated coding stage was followed by a final stage of axial coding that enabled me to assemble and recombine the emergent themes, as well as explore them according to the more expected themes I had anticipated from the literature review and interview process. The axial stage involved both inductively and deductively relating concepts and categories to the phenomena under study, the contexts within which the phenomena emerged, the actions that these phenomena are managed under, and the consequences of interactions between phenomena. Here, the wheat separated from the chaff, and valuable insights that could be shaped into recommendations for better design practices began to emerge.

\(^1\)See Huang (2011)
<table>
<thead>
<tr>
<th>Code</th>
<th>Frequency</th>
<th>Number of Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Augmented Reality</td>
<td>26</td>
<td>7</td>
</tr>
<tr>
<td>Budget</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Collaboration</td>
<td>31</td>
<td>9</td>
</tr>
<tr>
<td>Convergence</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Curriculum</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Digital Literacy</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Embodied Interaction</td>
<td>7</td>
<td>4</td>
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<tr>
<td>Engagement</td>
<td>26</td>
<td>10</td>
</tr>
<tr>
<td>Gaming</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>HCI</td>
<td>14</td>
<td>8</td>
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<tr>
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<tr>
<td>Location-Based</td>
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<tr>
<td>Meaning-Making</td>
<td>12</td>
<td>4</td>
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<tr>
<td>Mobile</td>
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<tr>
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<td>Simulation</td>
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<tr>
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<td>11</td>
<td>6</td>
</tr>
<tr>
<td>User-Generated Content</td>
<td>11</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 5.1: Code Frequency: *Code* indicates the code word used to tag a phenomenon or theme. *Frequency* indicates how often the code came up in the set of twelve interviews. *Number of Interviews* indicates the number of interviews that the specific code turned up in.

These are the final codes that arose through the axial coding process, during which a small handful of codes that did not link to more than one interview were dropped.
Chapter 5. Analysis of Interview Data

5.1.2 Explanation of Codes

After the first two passes of hand-coding and software coding, prior to organizing codes conceptually, tighter thematic areas began to emerge. I was partly looking for codes that corresponded with literature I had encountered up to that point, but I also began to gravitate toward codes that helped outline the positions explored throughout this thesis: notably, vision-based AR as a teaching tool; materiality in both information and educational digital media; collaboration between developers and educators in both informal and formal education; critical approaches to exploring the shift in user agency.
that increasing digital media in education is contributing to; and the role of narrative and storytelling in meaning-making.

Some of the first codes that came to the fore had to do with increasing user agency, mostly around questions concerning the development of software applications that put context awareness or user-generated content as an important feature. While these questions weren’t exclusive to the informal world, they seemed to take on greater importance in the informal world due to the fact that these interview participants tended to be aware of the increasing importance of users’ personal devices in interactions with exhibits (and spaces). The personal devices code mostly referred to mentions of
users, learners, or visitors taking advantage of mobile devices, although a few of the participants mentioned tablet devices (though not enough to warrant discussion here). Digital gaming wasn’t a really prominent theme either, but it did come up in nearly half of the interviews, and roughly across the spectrum of participants. Here, the subject of convergence - of different media types and technologies - came up frequently. Participants from the informal learning world, especially, brought it up as something that helps connect the public to the museum through media that is accessible across different devices and channels, even if they didn’t refer specifically to transmedia in doing so. Convergence, though not explicitly woven together with narrative, came up frequently when participants from the informal learning world spoke of narrative-focused exhibits or experiences.

Some codes arose out of questions directly related to augmented reality as a teaching tool. These were among the most prevalent. This included simulation, which most often came up around discussions of AR in science education, and whether virtual representations could stand in for material objects. Furthermore, immersive environments were discussed among participants from both formal and informal learning as potential bridges of AR and traditional analog media or pedagogy. While location-based AR wasn’t a primary focus, it seemed to be something that a few of the participants from the informal world were concerned about.

A number of codes related to HCI came out of interviews with both camps, although participants from formal and informal learning had very different concerns about HCI. Participants from formal learning, for the most part, discussed touch and screen-based interactions, while participants from informal learning tended to more frequently discuss what would be thought of as embodied interaction.

The subject of collaboration - between developers, educators, administrators, and both formal and informal worlds - came up with great frequency, most likely because some of the anchor questions were designed to elicit responses around this theme. It
also, however, tagged passages that described collaboration between learners, as well as between learners and family members.

Finally, there were administrative concerns that were expressed through comments about available technology **budgets**, adherence to strict **curriculum** requirements, as well as student and parent concern (mostly in the formal world) about **assessment**. Educators, especially, seemed particularly concerned with the subject of student digital literacy, possibly echoing concerns of parents. When discussing the educational merit of collaborative development practices, concerns about **pedagogy** came up time and again. Educators from across the spectrum were concerned that pedagogical concerns cannot take a backseat to entertainment, while participants from informal learning were concerned with making educational content meaningful and emphasizing the process of **meaning-making**. Meaning-making was tightly coupled with the subject of **engagement**, which also tied back to user-generated content and a number of other themes. But engagement of museum visitors was as big of a concern as engagement of students in the formal world. Teachers spoke of content that is not degraded, but remains captivating. That a theme like gaming,

### 5.1.3 Summary

I offer a more detailed summary of my findings and recommendations in the following chapter, but a summary of the coding process is in order. As I began the axial coding process, codes were categorized under the following headings: **content creation, design, and development; formal learning; informal learning; and new and digital media**. While strong themes had already emerged, this categorization process let me align these themes in a manner that was evocative to me before beginning to read and align interview data with specific relevant literature, and to begin the process of writing and documenting my analysis. It became apparent that certain themes did not, in fact, have a single natural home among any of the categories outlined above, or could be thought
of as “owned” by any one group of interview participant. These four categories became useful for aggregating codes, but also for making comparisons between categories. As very broad thematic areas, they became useful in my search for relevant literature, as each area has relevant and topical research literature that I was able to apply toward my analysis in a productive manner.

The reason for the discrepancy between categories (as storage containers for individual codes) and the emergent themes that I’ve aligned my analysis under is straightforward: many of the emergent themes are based on multiple codes that, quite often, sat in more than one category. For example, a theme like personal devices relates to multiple codes (user-generated content; mobile devices; user agency), yet also relates the categories formal learning, informal learning, and new and digital media. In this process, the themes that have emerged as the richest in the process of analysis are those that engage people from across the spectrum of participant groups, through multiple codes aggregate in more than one category. Educator and learner comfort with technology, another important theme in the discussions that is crucial to my analysis, especially with regard to the HCI questions this study negotiates, interacts with codes like HCI, mobile, pedagogy, and user agency, which were aligned in multiple categories as well. When themes like gamification or social media came up, I presumed early on that they would be recurrent. The fact that they were only brought up by a handful of participants is indicative of their connection to limited related or secondary codes.

As far as tendencies for specific groups to focus on specific themes is concerned, as can be expected, museum people brought up meaning-making more than formal educators, while embodied interaction and convergence were subjects that developers, for the most part, grappled with in a way that teachers did not. At the same time, developers weren’t forced to come to grips with curriculum or assessment, as educators were. While my recommendations and findings are highlighted in chapter 7, in order to summarize the coding process, I must first recognize that it has been complex, and only through a
constantly reflexive approach have I been able to find the connections between participant
groups, experience levels, technical capabilities, and disciplines. To boil it down, this
process didn’t lead me to hypothesize that screen-based AR is dead in the water, or that
embodied AR is the future, or that vision-based AR works best in physics educations.
Rather, the reflexivity of the process, and the constant comparative approach undertaken,
has reinforced my belief that the emergence of vision-based AR is a highly complex
subject, its success deeply contingent on dynamic relationships between educator and
learner, and that a multitude of factors need to be addressed in order for a body of
successful AR design practices to firm up. That said, it also reinforced that this a
technology and interaction concept that people in science education are talking about
across the board, so it pays to be approaching this study from such a holistic position.

5.2 Addressing the Thesis Positions

The following section addresses how interview participants are dealing with or thinking
about the two themes that have emerged as the central focuses of this thesis: That
vision-based augmented reality has the potential to be an effective tool in the arsenal
of educators using digital media in both formal (classroom) and informal learning en-
vironments; and because vision-based augmented reality is a technology that appears
well-suited for both formal and informal science education, developers, content creators,
teachers, exhibit designers, and curators - stakeholders from formal, informal, and devel-
opment communities - have opportunities to leverage their shared goals and skill sets to
create effective uses of this technology.

5.2.1 AR as a Teaching Tool

At the beginning of the interview stage, one thing I sought to do was determine whether
the data would establish a clear finding about the strength of augmented reality as a
teaching technology. As I questioned the interviewees regarding this subject, we frequently discussed whether different approaches to augmented reality were more appropriate for specific types of learning (and specific contexts). My own experience, and my feeling about the dialogue around augmented reality in the general media, led me to believe that vision-based AR, in particular, would be the method that could have the strongest impact on teaching and illustrating scientific concepts.2

Interviewees made some very insightful points on this topic. For example, Tim, a computer scientist with vast experience designing virtual reality, embedded simulations, and tangible interactions for learning environments, noted the power of AR as a representational medium:

> I’ve been trying to put kids into virtual environments much as you’re thinking about putting kids into virtual environments, and AR’s got tremendous possibilities for doing this sort of sharing the physical space of the classroom with a simulated phenomena. You’ve seen what Rose Luckin has done in an outdoor setting?3 Something like that. I think it ultimately comes down to representational choices, but I think AR has a lot of potential.

Tim’s comment sets the stage for connecting vision-based AR to previous digital representational media, like VR. Maya discussed screen-based AR (and other digital media), but from the perspective of a teacher who values interaction and social engagement between her students. An interesting thing that she brought up to me, that echoes Buxton’s

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3Luckin is a British learning sciences researcher who has studied a BBC AR storybook and storytelling kit, an ARToolkit-based project that created interactive texts. She was one of the first learning sciences researchers to focus on AR-enabled texts and the impact that they may have in classrooms. Her work that he is referring to has been written about here [http://www.guardian.co.uk/education/2006/mar/07/elearning.technology15](http://www.guardian.co.uk/education/2006/mar/07/elearning.technology15), as well as in Kerawalla et al. (2006) and Smith et al. (2007). It is described in greater detail in Chapter 2.
emphasis on storytelling (discussed earlier), is that the story, or the hook - whatever it is that is going to engage the kids - needs to come before the technology. “The trick is to get the kids engaged. Once they’re engaged, anything else you can add that will make them process information better is a bonus. That’s the beauty of these kinds of technology - they’re already familiar with it from elsewhere, but it still hasn’t lost its appeal.” On the spectacular value of AR, she noted that she doesn’t reduce this kind of medium to mere entertainment or spectacle, necessarily, but suggested that its value becomes more apparent as an educational medium when the technology takes a backseat to content.

I don’t consider this a spectacle. It’s different than having explosions, or Angry Birds, but yeah... I consider this kind of technology a useful tool. Really good tools that can get kids excited about science. If you can convince them that they can use their phones or tablets to do stuff like this, then that’s where the value lies, but I don’t believe that you have to entertain them to get them engaged. There have to be other ways - big discussions, controversial topics - stuff like that. Give them things to solve using the technology.

Looking at these comments from Tim and Maya (and paying respect to Buxton and others already mentioned), developers and content creators working with AR needn’t worry about the novelty or flashiness of their applications. They can be lively, animated, colourful, and even playful. In order to increase their effectiveness, though, attention should be paid to delivering meaningful and engaging narrative content. Nathan, who is a developer of interactive learning environments, sees the strength of AR as a teaching medium resting in its ability to eschew a linear narrative direction and challenge the flatness of information layering by fostering concept-based activities that transcend different methods of information delivery.

With AR, something I’ve been excited about is its power for storytelling or narrative creation. It’s common now that a key component to structuring good
transmedia\textsuperscript{4} - and transmedia can be stretched from museum experiences to books - is that you’re no longer crafting a book, but trying to make a game from the book. You’re creating an interconnected world. When it takes the form of a book, books have their own trends and values. In the form of a game, you won’t be dealing with a direct, linear narrative in the sense that games include choices and are interactive. So this notion of world-building around a concept or story becomes ever more important in this type of scenario.

Based on his emphasis that AR is a powerful medium for storytelling, there is an interesting question about its purpose: is AR a narrative-enabling or narrative-making technology? Nathan works with interactive digital media, I should note, so it is unsurprising to see him privilege exploration of the interactive affordances of new and digital media over analog media. For many readers, listeners, and learners, analog media offers the same affordances for crafting interconnected worlds, linking stories and characters, or exchanging sites and contexts for other ones, but these affordances are enacted in the minds of the users, not necessarily in the gameplay.

Donald, a museum researcher with a deep understanding of science education both in and outside of science centres, put it like this: “I often chant a mantra that the curriculum, particularly the science curriculum, is a manifestation of the human experience of the real world. There’s all kinds of things going on out there that we attempt to explain by invoking the sciences, but we contextualize all this in the boundary of a very artificial environment - the classroom - so pushing those boundaries back and having digital media as a mediator of those naturalistic experiences can only be beneficial to the learning process.” Henry, who is an administrator in a science centre, but is also equally involved in museum research, was more reserved when asked about the presence of virtual objects in material environments, although not unequivocal: “I’m not convinced that virtual experiences work well within a social environment, given that we have a history of trying

\textsuperscript{4}See Appendix B for a definition of transmedia
to create physical activities that are tangible that haven’t been successful. I’m just not convinced. But there are times when it’s just so powerful, when it brings a fairly flat material alive.” Text-based and 2-dimensional information delivery is not automatically ‘flat,’ but the vivacity of the tool is something I will return to when considering comments from Jocelyne, who noted the capacity for AR and similar technologies to illustrate phenomena, like the entire life cycle of an organism, in ways that cannot be done when observing an object in real life. AR can challenge longitudinal temporality or introduce contextual variables to material objects in a way that cannot be done otherwise without leaps of the imagination or suspension of disbelief.

Yoon et al. (2012) conducted an insightful study on science museum field trip visits by students in grades 6, 7, and 8 in order to understand whether any impact on conceptual or cognitive gains could be correlated to the use of AR in exhibits. They found that “although students in the augmented condition did not spend a significantly longer amount of time interacting with the enhanced device, the fact that students in this condition did show a significant increase in conceptual gains over students in the control condition indicates that the augmentation may have enhanced conceptual understanding.” Furthermore, their research suggests that students in the augmented condition demonstrated significantly enhanced ability to interpret the scientific phenomena. They suggest that characterizing digital augmentations as learning scaffolds has been fruitful, especially in light of work by others in the learning sciences who have studied scaffolds embedded in digital platforms, such as Quintana et al. (2004).

From a somewhat different perspective, but also cautious about how AR and virtual experiences have been presented as a screen-based medium in science centres, was Mike, who is a programmer and designer developing interactive exhibits for science centres and museums. He suggested the following:

*There’s quite a lot of screen-based and flat entertainment that we have access to all the time. Losing focus on tangible experiences would make some visitors*
to science centres question “why are we coming here again?” So, I think you have to keep a lot of those larger electromechanical types of exhibits because they provide the type of spectacle that visitors have come to expect from science centres, but there’s a lot more that can be done. Now that multipurpose computers have become relatively cheap and ubiquitous, the typical technology approach to those older science centres, which tends to be a lot more based on industrial automation, makes it a bit more feasible to start putting more computing power into each exhibit, and perhaps containing more interactive possibilities than it previously did.

Rogers et al. (2002) suggest that some of the characteristics of good interaction design include placing usability at the fore, taking into account what users are good and bad at, and strongly considering the things that the design might be able to help users do or understand. Is it necessarily more interactive to include virtual technology when pulling gears or twisting knobs can accomplish the same goals, though? Maybe the crafting of interconnected worlds that good transmedia affords (to which Nathan alluded earlier) comes into play here. Or, as Henry and Jocelyne suggested, introducing virtual elements may enable views and scenes that simply cannot be represented otherwise and, as a result, might stimulate students to try to understand what is going on with the exhibit or artifact, or discuss what might be going on if it’s something they would not be able to see otherwise.

Contrasting these cautious responses from the science centre world against the earlier, more decidedly positive ones from the formal education world, it might be tempting to assume that informal people are tip-toeing toward incorporating this technology, or are, dare I say, more protective of their existing technology and environments, but teachers and school administrators appear equally protective of their curriculum and the sanctity of their classrooms, as both Jocelyne and Maya, the two teachers I interviewed, noted. What both Henry and Mike agreed on, however, was that there are appropriate times
and contexts when virtual representations seem to “just work,” and we should be careful not to generalize across contexts.

One comment about the power of AR to illuminate unseen processes resonated with me in particular. It came from Ueli, who is situated, perhaps more than all of my other interview respondents, in a position that enables him to understand the technology (as a developer) as well as the learning objectives in both informal and formal worlds (as both an educational technology researcher and a museum researcher). In addressing directly the subject of how AR might be used as a learning technology, he offered the following: “I would imagine that, at least in a science centre, AR could open up all these black boxes that you have. *What goes on inside of this engine?* Or *what goes on in this physical phenomena?* Furthermore, you can use AR as a tool for visual enhancement that lets you see and understand processes on an atomic level. There can be an extra level of mediation than what is already there.” This is not to say that analog technologies can’t do similar things, however. Many science centres and classrooms have readily-available microscopes and similar instruments, as well as apparatuses like clocks and engines, sheathed in transparent coverings, that let viewers see their internal workings. But the ability to cycle through multiple views, or animate sequences, is something that virtual media can do “on an atomic level” in a way that analog technology cannot. This is where AR really shines as a tool to enhance science education, not just in its ability to help visualize and represent things that learners might have no other way of seeing - without forsaking the material interaction that an environment like a science centre and its artifacts, or a classroom and its social dynamic, can foster - but in the sense that it can provide a platform upon which users, visitors, or learners can add manipulable or interchangeable information layers.

This is not trivial, though. In order to effectively visualize and represent these things that learners have no other ways of seeing, skilled 3D modellers and animators will have to be employed, or private firms that specialize in this area will have to be contracted.
The cost, as one might expect, can be significant. Furthermore, adding manipulable or interchangeable information layers, if attached to cost recovery by the AR platform\(^5\), can make it especially challenging to enable public contribution through user-generated content. It is simply not yet feasible for developers in these environments to be able to process multiple images gathered through computer vision in a cheap and easy manner at this point in time. That said, it gets increasingly easy with time, so the potential for future applications to enable this should not be written off.

**Location-Based versus Vision-Based**

While none of the comments so far make a particularly strong case for vision-based AR over location-based AR, there are technical and spatial constraints with location-based AR that should be taken into account in most learning environments like school classrooms or science centre exhibit halls. Ueli pointed out that “the embodied experience would be something that is really important to get right in order to understand the mobile device in context of the space that is being used, particularly if you have content or media that is location-based, or triggered by proximity - and for the museum space, that is really important.” Pallud and Monod (2010, p. 568) echo that embodiment is perceived as a necessary criterion to have a positive experience in museums. But what does Ueli mean by embodied experience? Knowing that his work frequently deals with the human-computer interaction technique known as embodied interaction (as coined by Dourish (2001) - see Chapter 3), and knowing that it has a deep phenomenological influence, I would suggest that he means multi-sensory as well as physical, mobile, and context-aware. The application should be able to position a user in a space and deliver content that is appropriate to that space. He was dismayed after having evaluated Layar for a location-based application, noting that, aside from concerns about its lack of precision in a bounded, indoor museum environment, the interface “didn’t really convey the topics

\(^5\)See the comments about Layar Vision or Moodstocks in Chapter 2, for example.
and information” that he was hoping to get across. (He didn’t elaborate, but knowing that his group also does a lot with rich 3D animations, something that Layar only began supporting in 2011 - and still doesn’t come close to the capabilities of Vuforia or String with the Unity 3D integration - this could be a reason for his dissatisfaction with the Layar platform.) That said, there is a considerable challenge to using GPS-based AR in a museum or school. The placement of objects or number of devices trying to connect to a local wireless access point is generally not the issue here. Kjærgaard et al. (2010) outline some of the misconceptions and challenges with using indoor GPS positioning, but they highlight the point that both the number of walls and construction materials used in a building can each have a significant impact on signal degradation, something which is crucial for museum and school developers to consider.

Ben, an AR developer and biomedical communications expert who has created a number of location-based AR layers using the Layar platform, and who is intimately familiar with this subject having explored location and context-based development for hospitals and similar institutions, commented on the advantage of using either vision-based or marker-based AR in these environments:

*It does address a very real problem, which is that GPS doesn’t generally work indoors. Without vision awareness, you really don’t get the context awareness you’re looking for in interior environments. But I think eventually you will see some additional cueing systems, where you don’t actually walk around with your camera running, with your device connected to the internet - which can be a little invasive.*

While he was not specific, what he likely means here is the use of biometric data collection - eye tracking; gesture; gait analysis; voice recognition - to determine mood and other contextual cues that can then trigger different content layers. Li et al. (2009) provide background on this particular subject. At the end of this statement, Ben hints at something that often gets left unsaid about location-based AR - that it frequently
requires pointing a device like a phone at people, buildings, or scenes in a way that can raise alarms or cause tension.\(^6\) Furthermore, both Ben and Tim brought up the tremendous tracking potential inherent in location and context-based AR, although Ben seemed more concerned about the privacy and surveillance angle, while Tim was more interested in building context-dependent interactions that would require knowing where and when students were moving around a classroom. He was excited about being able to track kids for the purpose of driving simulations, where their position relative to an artifact or zone in the classroom would have some meaning in the activity they’re engaged in (an HCI approach that could lend itself beautifully to a mixed reality experience).

### 5.2.2 Bridging the Formal and Informal Development Communities

Because vision-based augmented reality is relatively young in terms of its adoption by the general public, the question around how developers, content creators, teachers, exhibit designers, and curators - stakeholders in formal, informal, and development communities - can learn from each other as they build with this technology, is relatively uncharted. Others have envisioned interdisciplinary communities of practice that foster collaborative relationships between designers and content creators around new media design for museums, that don’t necessarily privilege designers over non-designer stakeholders (Kocsis and Barnes, 2009). While still acknowledging these interviews, I set out to explore whether current trends that digital media creators in educational environments consider are a break from what the literature has documented about the introduction of laptops into classrooms, or screen-based exhibits in science centres. Furthermore, I wanted to

\(^6\) The recent alleged assault on Steve Mann, a pioneer in computer vision, augmented reality, and wearable computing, who is known as one of the world’s first public cyborgs for his EyeTap support headset and glasses - which are a precursor to Google’s Project Glass\(^7\) - in a Paris McDonald’s restaurant is merely one possible scenario regarding the response AR users may encounter as the technology matures and, possibly, becomes more embodied. [See](http://techcrunch.com/2012/07/16/augmented-reality-explorer-steve-mann-assaulted-at-parisian-mcdonalds/)
ascertain whether an opportunity to build on a shared set of tools and practices, appropriate for both formal and informal contexts, existed, and whether I could contribute to recommendations for better AR design practices in learning environments going forward. Can these groups leverage their collective goals and skill sets to create more effective learning tools and engagements, or learn from each other’s mistakes and successes, as general digital media development practices mature? At their disposal is a growing body of resources supported by a community composed of game developers, commercial design and marketing developers, and artists. What opportunities for collaborative exchange might exist, and how would my interview participants interpret these opportunities considering their different backgrounds and responsibilities?

Ella, who, for a number of years, was involved in designing a multi-institution graduate training program that brought together education students and computer science students with teachers and informal learning educators, echoed points Maya made about engaging students with the content before thinking about engaging them with the technology. Ella described how the project got graduate students to look for what would interest and stimulate students. “They had to really discover what students were interested in, and then work directly with a teacher to tease out something that technology could help answer a problem to. So, go in, interview the teacher, observe the classroom, see technology not just as ‘oooh we can do it, so we should do it!’ but, like, ‘let’s find something that the teachers find hard to teach,’ or something that the students aren’t getting year in and year out.” This is an interesting contrast to what I feel both Maya and Buxton (in his previously mentioned talk) proposed: whereas they are both concerned with forming narratives before developing technology, Ella does not reduce content to narratives. Her group was looking to technology to help solve a problem with the content but, as she and others made clear in these interviews, it is a complicated process to negotiate how much of the original content can be enhanced or augmented by new technology when the content is problematic for one reason or another (i.e. it is not well
designed, or too difficult for students).

She noted the challenge of working collaboratively with new teachers: “The first year we taught it, we had initially imagined this being a class that the pre-service teachers could participate in, but combined with their insane schedules and, finding those pre-service teachers that we worked with were simply lacking in the experience of what was actually needed in a classroom to implement technology, we found that the teachers who had been teaching for 5 or 10 years had a much better grasp of where there were gaps in the curriculum.” When asked if the newer teachers had problems with the technology, she responded that it was not the technology. “It was definitely with the curriculum. A lot of our more expert teachers had very little experience with technology. Some of them, in particular, wanted to be involved because they didn’t use technology in their classrooms and they wanted some help in implementing its use, as well as help to really start thinking about how they could be using technology in their classrooms.”

This point doesn’t just speak to a lack of experience with either technology or the curriculum, but to different levels and styles of training with both the curriculum and technology. Tim commented, that “it may not always be chronological, but there’s a style difference. Younger teachers are more likely to have been involved, when they were in pre-service training, with a curriculum in which something like inquiry was described and discussed. Older teachers, for the most part, didn’t have that training.” With a generational shift in teacher populations, adoption and acceptance of technologies like AR as pedagogical tools could be heightened. Pegler et al. (2010) offer evidence summarizing research that finds younger teachers demonstrate confidence and a higher degree of technology integration when new classroom technologies extend into the personal or social sphere. So this isn’t necessarily a generational thing, as Tim pointed out, but a challenge to accommodate different experience levels and teaching styles that adapt according to both teaching experience and technical competency. There is a subtle balance between

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8“Pre-service” in this context implies student teachers who have not yet started teaching.
understanding how to deliver curriculum, being comfortable with new technologies, and being able to accommodate both. There is a definite sweet spot that I think both Ella and Tim are each working toward, and having varying degrees of success depending on the contexts within which their research is situated.

Ella commented further along this vein, but drove home a particularly resonant point, that this type of collaborative, multidisciplinary exchange requires a deeply complex assemblage of relations, discussions, practices, artifacts, and exchanges.

*What we really came down to at the end, was that nobody is ever going to become an expert in the other area, but finding ways to learn to appreciate and talk to each other is crucial. For the education team, or the computer scientists, getting them to talk to each other, and to really start engaging with the teacher or the educator about what technology can do in a classroom or in a learning environment, is critical. Far too often when we’re developing technology, we don’t ask the bigger questions about what the heck it’s meant to be doing.*

Because her project had to do with introducing a new technological medium into a learning environment, our conversation didn’t directly address how best to use the technology, or how best to introduce the technology as something that supports content, but her emphasis on the complex and dynamic nature of the relationship that exists between collaborative development, content, and new technology opens this line of enquiry up. We don’t always ask the “bigger questions” about what the technology is meant to be doing because, as developers, researchers, and content creators, we are often learning as we are going. A colleague of mine made a spontaneous comment once that I find startlingly relevant here, stating that “educational software is in constant beta state.”

This is partly a question of training, but also a question of determining how well-

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*The term beta, as it applies to software, indicates a state of feature completeness, but a lack of testing, reliability, and general readiness.*
rounded the developers or content creators need to be for such context-specific work. Henry expressed how, despite having a PhD and having experience working in science for a number of years, it was a completely different environment when he embarked on his current career. “There were very few things that prepared me for working at the science centre. I would say that you have to have an understanding of a plethora of different knowledge sectors. My theory is that you’re looking at a cultural basis for knowledge.”

Finding a cross-generation, context-agnostic, technology-neutral common language by collaborating with really well-rounded partners is surely challenging, but Charlotte, as a science museum administrator, commented that it’s “really, really refreshing to be able to communicate with someone who’s in our field, who’s an information technology specialist, but who also comes from the science museums field, so that they can help materialize your ideas. They understand a discipline, but they also understand the museum environment.”

But does one need a biology PhD and a toolkit of programming skills to work as a developer in a science centre? Or a wide array of digital graphics expertise and a background in art history to develop for an art museum? Not necessarily. Even without a particular disciplinary background, developers and researchers can gain a tremendous amount through spending an extended amount of time in the environment or context they will be working in. Tim, as a computer scientist with a responsibility for training graduate students, gave the following advice to prospective researchers and developers looking to understand how to bridge this gap between background and technical competency:

> Getting on the ground and being with the kids in classrooms, and really getting a feel for what the culture is like - and it’s going to vary from place to place - helps you really get a feel for an age group. I think developing that context awareness is really important. If you’re going to be a researcher and do this sort of stuff for the long term, you have to have the trust of the kids and the teacher. If you’re going to do classroom-based research, there’s just no way around it.
Of his own graduate students, he noted:

“They serve multiple roles. They’re there to fix equipment if it goes down, but they also know the instructional narrative, and they know where it’s going. They work with individual groups of kids, so they’re very active when they’re called upon to be. In case we don’t want them to have that connection, though, they won’t, but I think the experience on the ground really helps them. I think it really informs their design decisions.”

His graduate students, it should be noted, have frequent opportunities to work with educators from both the informal and formal worlds, as do graduate students working with a number of the interview participants I spoke with. Each environment is different, though, so there is no way to say unequivocally how the experience for a graduate student or early researcher might differ in a classroom or an informal learning space. Donald lamented that “some museums are highly collaborative, and some are highly territorial and dysfunctional in their communications, so that’s a very difficult thing to generalize about, other than that you would hope the general principle driving everything is collaboration for better outcomes.” However, when asked more directly about possibilities for collaboration, not just between developers or researchers and science centres, but between schools and science centres (but not museums in general, it should be noted), he offered the following: “I think that science museums are more disposed toward collaboration, and the reason for that is, number one, we’ve got a situation where the science centre in many ways mirrors or matches the curriculum connections in the school curriculum. The connections between schools and science centres are very nicely situated, and science centres are offering, for the most part, many experiences that schools don’t have the opportunity to readily replicate.”

Jocelyne, a primary school teacher who has been involved in a large, multi-year and multi-institution collaborative curriculum design project that brings virtual technology into her classroom, commented on the differences between formal and informal learning,
as well as the possibility for collaborative exchange between the two worlds in designing
digital media that traverses these boundaries. In her world “it can’t be that totally
casual, immersive, take-as-long-as-you-want thing that it can be in a museum workshop or
something because math starts at 2pm.” But she still saw opportunity for collaboration,
suggesting:

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\text{I think it would be really worthwhile. I can imagine a co-design meeting with an educator from a museum, let’s say, where some particular science strand would provide incredibly rich interaction because of that difference... because they have the whole day to go deep and get messy, but we have to block it off into 45 minute chunks. How can their ideas help us enrich those 45 minute chunks, and how can some of the curriculum connections and time deadlines that we have to meet also make their way into the museum curriculum so that they enhance each other?}
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Describing the large collaborative digital media project that she has been a part of for
the past year, she noted that she has had an opportunity to learn a tremendous amount
about the development process, while still remaining true to her particular interests and
goals:

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\text{There were so many positives. You get that many highly invested, intelligent educators and design people around a table and every one person’s ideas are going to improve someone else’s ideas. I found it so rich in terms of what we were able to design by putting all these heads together. But even just as a personal learning experience, it was really neat. Design is not what I think about. I think about the design of my classroom, and how to design great activities, but to think so deeply about each step of the process - like I mentioned, a 30 minute conversation on what type of animations we should use could be this teeny detail - I just found that it enriched my experience and}
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understanding of the entire process to be part of all these small and important
decisions. On the other side, I think a difficulty was that, as a teacher, I’m
always going to do what’s best for my students. I’m always going to respond
to whatever problem comes up in a way that best meets my students’ needs in
the moment, to keep all of those priorities in mind, and that can be difficult
with a long-term project that has a goal, where timing is an important issue.

Emerging here, between her and Donald’s comments, is a critical point: stakeholders will
safeguard their own interests, no matter what, but that should not stand in the way of
their participation in these inter-institutional and cross-discipline collaborative projects.

Ella, however, echoing some of Jocelyne’s sentiment, cautioned about the vast amounts
of time that can frequently be spent dealing with “teeny details” that end up determin-
ing what kind of virtual representations will be used, when designers, programmers, and
educators all have particular tropes and metaphors they are familiar with. She described
how the computer science students she interacted with in designing technology for a
mathematics lesson would

...jump on gimmicks very quickly. So they had this whole thing with monkeys
and bananas, where students would move bananas from bunches, subtracting
by tens and that sort of stuff. This is a metaphor that doesn’t really work
when you’re teaching subtraction, but one of the group members had spent so
much time doing the visuals for this that, all of a sudden, we were stuck down
this route. When it’s like “oooh... this doesn’t quite work” for the complexity
of what you’re trying to teach, what do you do? That’s such a classic problem
for everyone designing technology.

She noted that this problem wasn’t just tied to the amount of time spent preparing media,
but had a lot to do with the developer’s previous learning experiences: “I think it’s really
easy to revert to what you think works, or to how you learned it, or to some image that
you saw in some other media, be it a book or a video game or something from your past. Developers frequently revert to these things before even getting to the point of actually exploring the issues that are at hand. In our case, this whole moving tens and ones across was way more complicated, and they needed a metaphor that wasn’t so constrained, but I’ve seen this happen so many times. We often forget that the content has to be the driver behind the technology.” This is a really crucial point, especially seeing how it relates to her earlier point about finding ways that the technology can help solve learning problems. It’s not the technology that is going to solve them, though. In this case, it’s a careful mix of technology, experience, appropriate and considerate design, and engaged stakeholders. Finding this sweet spot is the dream of any educational technologist, and I think that Ella, of all people, is clearly in favour of nurturing the sort of holistic methods that move in this direction, rather than, say, blind technological determinism. That said, reconciling these disputes can eat up countless hours of design time, money, and patience. How different tropes, metaphors, and representations that are familiar to formal educators emerge in design discussions may also be a challenge for developers and educators in the informal world.

5.3 Emergent Themes and Discrepancies

A number of themes emerged through the coding process, especially during the axial stage, when concepts and categories were re-aligned and tested for links or breaks. These emergent themes include: the weight of curriculum; the powerful role that assessment plays in a learner’s comfort with new technology; educator and learner comfort with new technologies; opportunities to incorporate personal devices in both formal and informal environments; the value of social collaboration mediated by applications and technologies; and the relationship between materiality, simulation, and interaction. While the previous section addressed the foundational positions of this research, these additional
interesting and salient points emerged organically through a deep and repeated analysis of the interview data. No one theme is dominant, or leads to more beneficial design recommendations, but they are interconnected and inform subsequent questions.

5.3.1 Curriculum

The deeply imbricated relationship between consideration toward curriculum and novel teaching approaches profoundly affects the success of digital media implementations in educational contexts, both formal and informal. This topic came up a number of times, in a multitude of different ways. Jocelyne, whose teaching is rooted in an inquiry-based approach, favours a holistic approach that equally values curriculum, technology, and hands-on experience: “I say the goal, as much as possible when I’m teaching science, is for students to be having experiences with the natural world and the real world that are as hands-on and guided by their own questions as humanly possible, so most of my inquiry units always have a very deep rooting in natural experiences, in being outside, in using whatever technology is available to bring what we’re studying into the classroom.” Her approach is grounded theoretically in the work of constructivist scholars such as Dewey (1938), who pioneered experience-based approaches to pedagogy.

Maya, noted that a subject like anatomy is amenable to this kind of digital media mediation, suggesting that the biology curriculum could easily be molded to fit the digital content. After describing my idea for an AR application designed to see inside technoscientific artifacts and showing her an example of the FLOOPS application I was building at the time (described in chapter 6), she commented that she would like to adopt this idea of using AR to view inside things and see invisible processes - which connects with Ueli’s previous comments about AR scenarios in science centres as a means of opening up black boxes - as a means of augmenting bone samples with virtual content in a class on adaptation and evolution. She outlined a specific scenario that would work for this.

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10See Appendix D
type of lesson:

So, we start with the bone samples, but we have layers of virtual information that can be triggered when a student recognizes, for example, that something is an example of human evolution. You could start with a row of skulls, which we physically have (here in the school), and the layers of information depicting how they link to each other, how they are different, and what the different stages represent, would be digital. Imagine... you’re a student, and when you ask “what is this thing I’m looking at,” you can go discuss appropriate questions and confer with other students based on the digital information that is triggered. Or, imagine it like this: the skulls are disorganized, but groups of students have to re-organize them by using information they’re getting from the augmented reality application.

One might ask why this couldn’t simply be done with text books or similar materials. What might the interaction with a tangible artifact like a skull, mediated through some sort of viewfinder that can deliver virtual content, afford? I believe the simplest answer likes in the ability to produce multiple layers of inter-changeable augmented content that can be accessed with the push of a button,

Adapting technology to fit the curriculum - or vice versa - isn’t so cut-and-dried, though, especially when designing technology that works with curriculum that cuts across the formal and informal divide. Nathan suggested:

Anyone who actually creates education programming in a museum setting will tell you that, quite often, the problem with defining these spaces as learning environments is that the emphasis on learning is tacked on as an afterthought. Developers will give a cursory nod toward the local formal curriculum structure. But then validation of the supposed learning is somehow dictated by the curriculum standards. You have this loftier idea that learning is happening,
Chapter 5. Analysis of Interview Data

that knowledge building is happening, but in the end, who gives a shit whether the curriculum says it’s learning!

Nathan is right that the relationship between technology, curriculum, and environment isn’t always a cozy one, but there are certainly reasons that local school curriculum and science centre content frequently speak to each other. These reasons include everything from funding source requirements at the private, civic, district, and national levels, as well as the fact that school field trips are a good source of money for science centres and, consequently, require science centres to be contextually relevant (Price and Hein, 1991). So Nathan might not be giving enough credit to those in the museum world for their continuing contribution to learning, but he also may be alluding to something bigger about the complex and changing dynamics that govern the relationships that publics have with these institutions, particularly around this subject. Wyman et al. (2011, p. 462) suggest that museums convey authority through their existence. “We cannot claim that trust in the institutional voice (of the curator or the museum storyteller) has eroded, necessarily. People still believe in the experts. But the voice of the expert exists in a much louder world, information-wise, and that din has been brought into the once-sacred realm of the museum. The only real change in this new forum obliges us to go where these conversations are taking place rather than waiting for them to come to the museum.”

5.3.2 Assessment

The concern that educators have about satisfying curriculum mandates was made more pronounced by the teachers and developers working in formal education, among my interview participants, who felt constrained by the stress their students express around being assessed. This is especially notable around concerns about time constraints and peer and family pressure to attain high marks.

Ueli commented that “when teachers come to the phase of assessment, there are a lot of things during the day that suddenly become limited by the institution. This can limit...
some of the work that you’ll see, such as collaboration, or peer-based assessment. There’s a lot of tension, because assessment tends to be very individual, but we keep trying to come up with things that are very collaborative, and that could be a real problem in these new digital media environments.”

Maya also emphasized students’ concern about assessment at her school (which, it should be noted, is an exclusive preparatory school that has an extraordinarily high percentage of students going on to exclusive universities):

   In this particular school, the kids are very mark-oriented, so they act like the only thing they really need to do is whatever is required to get the mark, and the love for learning is absent, and that is a real problem. They just don’t have the attitude of ‘I’m curious, I wanna know more’ because they often just don’t feel they have enough time for that.

This would not be as important a consideration to this research if it did not have an impact on how those same students consider using learning technology outside of the classroom. “What grade will I get for trying this out at home?” appeared to be a common concern that students had, and would act as an impediment to adoption of things like mobile AR apps that could be used in both formal and informal worlds. While this is something I expected, I did not anticipate that it would figure prominently enough to dissuade educators from even entertaining the thought of using these technologies, but it appears to. If educators in the formal world are reluctant to take the plunge, the possibility of developing technology that connects the two worlds is greatly diminished.

5.3.3 Personal Devices

What is the role of the personal device, be it a mobile phone, tablet, or other digital media technology, in a learning environment? How is this role changing? Will school children learn a certain set of technology-influenced social dynamics in addition to curriculum
content mediated through the personal device? The idea of personal devices (which I’m treating as media devices brought into the learning environment by the learner or visitor that can be used to interact with content in the environment) came up numerous times in interviews, across all sectors, and ended up being a hot-button subject. These questions are crucial to this research for a number of different reasons. First, in order to engage in effective AR experiences, learners need to get accustomed to viewing these kinds of experiences, and that will happen on their own devices for the most part. They need to start seeing AR outside of learning environments, and become familiar with the technology, something that I suspect will happen slowly unless a real game-changing technology comes along. For now, the notion that youth will parade around holding mobiles or tablets in front of their faces to do anything other than text or play video games seems dubious. But the suggestion that they could use their personal devices for learning, both in and out of the classroom, if the media is accessible and tailored to their needs, seems less questionable. How did my interviewees respond to this subject?

Ella stated that she found it “really hard to believe that there is going to be any other direction in the long run. For me, the most useful approach to personal devices is that you bring a device that has your own content on it that you can somehow securely share with a larger device, screen, or whatever. You should be able to pass it around, use it to illustrate what you’re talking about, or send your own content and work to and from it.” She further added “I think it is going to deter administrators, but I don’t think it should. The use of personal devices opens up the possibility to see formal education slowly merge more with the worlds that we live in outside of it, and the reality is that we all live in worlds where we bring devices to and from different places.”

This comment connects with others that address the idea of education as part of a

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While this statement may seem to conflict with my call for more embodied interfaces for AR, it is, at the moment, a reality that AR is very much a screen-based medium. I think non-screen-based technologies for AR are too nascent in terms of their development - not to mention, unavailable for mass consumption in most cases - it is simply to early to predict whether youth in the near future will use mobile devices differently, or switch media preferences altogether.
continuum that extends between and outside classrooms and museums, forming connective tissue between them while, at the same time, exploring how pervasive digital media can engage learning in their interstitial spaces. Ella made a really salient point to tie these connections together:

*I know these students are not going to graduate and go do jobs where they’ll have no connection to the world outside them, so I feel like one of the things we’re shrinking back from as educators is helping students develop the skills they need to live in an interactive, networked society, and by saying ‘oh no, please don’t bring your personal devices into the classroom because it’s too messy,’ we continue to do that. The connection between formal and informal spaces is deep, and to a large extent it really just revolves around the question of how you get things from the classroom out and how you go about bringing the home life in. But what about the space in between? Can we use technology to create a bridge, or to create something new, because it exists? Is there some way of changing schoolwork into something that can be done on the bus on the way home? A type of activity that doesn’t belong in either space? Until school isn’t seen as something separate, the need to create a bridge toward museums and informal education, to slowly move school into informal, move home life into informal and formal, until maybe they’ll all eventually merge together, this will continue to be a problem. I don’t think this merger will ever be easy, though.*

Perhaps as emphatic as Ella about the likelihood that formal and informal spaces are going to have to get used to this possible future reality was Mike, who offered the following:

*With regard to bringing personal devices into an experience, I think that that’s one of the things that museums these days have to acknowledge is happening.*
It’s one of the things that they did acknowledge at a science centre I worked with recently, that, within a connected world where information is so readily available, they would be foolish to develop an approach to science centre content that neglects this total information access. Kids are going to be able to access more information, and perhaps richer and more detailed information about a subject, on their own through the use of a tablet or phone.

That said, he was overly cautious about designing experiences that rely on personal devices to mediate them.

I think that, on one hand, there’s still a large majority of the population that doesn’t have these devices, or doesn’t feel comfortable using them, and I don’t feel like they should feel excluded from any one experience. But at the same time, you can’t ignore the fact that people have come to expect a multi-modal experience. It’s not just what they deal with right at the exhibit level, but they want to maybe pull out a tablet and have a virtual experience that augments on top of whatever they’re looking at, or pull up contextual information, or maybe there’s some social media channel that’s attached to whatever it is that they’re looking at giving them the ability to comment and leave a message and attach to whatever it is they’re engaging with. There’s a point where that’s gonna be expected. The safest thing the institution can do is make sure that they deliver a solid experience without that type of technology first, but also think about how additional layers can be built on top of that experience while making sure that people who don’t have that technology, or who do have the technology but don’t feel comfortable using it in that setting, aren’t excluded from having the experience.

Surprisingly, the question of whether a personal device should be a mobile or tablet rarely came up, despite my repeated distinctions between the two in interviews. It is
especially surprising when taking into account the considerable differences that each kind of hardware affords. Is one more appropriate for a particular context - tablet for classroom and mobile for museum, for example? Jocelyne emphasized how her students are too young to effectively use mobiles and, despite having considerable time to acclimate to having tablets in the classroom, still had challenges with the user experience.

There are little things, like the fact that iPads and tablets are really difficult for students to write on. That ended up being an impediment in our work that we just didn’t imagine, but they have teeny little hands, and they press the wrong buttons, and then they press send and the exercise gets saved. Those seem like minor technicalities, but they’re technicalities that end up decreasing the motivation of the students when something goes wrong.

Could it be that, for really young learners like Jocelyne’s students, more image-based user experiences should be emphasized? How would a gestural interface accommodate image swiping, for example, rather than textual input?\footnote{I draw here on personal conversations I’ve had with Rhonda McEwen, an assistant professor at the Faculty of Information, about her recent research using iPod and iPad devices by non-verbal autistic children at a Toronto school.} This is all particularly relevant to my research question dealing with vision-based AR as a useful science medium, should the devices required for AR move away from the mobile or tablet base, toward glasses or more embodied and embedded devices.\footnote{While I have been very loosely lumping all tablet experiences and all mobile handset experiences into two rough categories, I should note that operating system differences, as noted by Nathan, can be a real challenge for developers. While cross-platform deployment software like Unity 3D can bridge this difference, developing for Android and iOS, the two most prominent mobile operating systems, are considerably different experiences, requiring fundamentally different programming skills and often considerably incongruous design practices.}

5.3.4 Educator and Learner Comfort with Technology

Jocelyne’s earlier comments about the difficulty that her students had holding and typing on tablets at the same times opens up an even more challenging question around device
and user interface familiarity. Tim, in addressing the subject of whether the kids he deals with in urban schools are willing and able to embrace new technologies, suggested “the kids have always been eager to embrace these. Every single time. So it’s easy to convince yourself that you’re doing something great, because the kids always like the technology.” But just because they’re willing to, or because they like the technology, does this necessarily mean that they can understand it? (One must keep in mind that he is a computer scientist who leads a development and design lab specializing in building this kind of technology.) How well does the familiarity that comes from having an iPad or mobile phone available in the home translate to its effective use in a learning environment? Ben suggested that “there’s nothing quite like a sense of ownership to produce motivation, and also work to increase your comfort level. A lot of it is just plain old experience: people are good at using technology because they buy it and then they try it out. It’s not that they have actual training, and sometimes it’s just experience in the medium.”

Can developers, administrators, educators, and the like just expect kids to jump in the shallow end, though? As with the introduction of any new technology into an environment where it is, at first, seemingly out of place, there is a gestational period that needs to be taken into consideration. Jocelyne commented that she “couldn’t wait for the moment when the process of learning the technology was finished so I could literally just step away and let the students run everything by themselves.” Despite this, she was unequivocally in support of this sort of engagement - of allowing her students ample time to learn the technology - ending our interview with the following statement:

> It’s the way our world is communicating. It’s the way people are making advances. You’d be staying in the dark ages if you didn’t help kids embrace and learn while they’re young and sponges, because those are the skills they’re going to need. And these technologies can bring fabulous things into the classroom that would otherwise be impossible. I think it takes confidence on the part of a teacher to embrace it and learn it and to know that it can enhance
and not detract from curriculum, and it’s certainly more work to learn, but it’s very worth it.

5.3.5 Materiality, Simulation, and Interaction

The interactive capabilities afforded by new media technologies in educational contexts are wide and varied, from simulation, to communication, to convergence of multiple technologies (Collins and Halverson, 2009, chap. 2). But are virtual/digital objects any less “real” than material ones when they are still composed of particles that dance on screens or are suspended in motes of dust. An interesting question for me throughout this research has been how we might train our minds toward thinking that virtual contexts are “real.” What sort of embeddedness of infrastructure or invisibility of content is required to force a suspension of disbelief in a learner’s mind? The objects that we study are implicated in the realities they produce by the ways that we look at them, the tools we look at them with, and the contexts and environments they arise in. Simulation often came up alongside themes of representation for me. Is representationalist thinking about how we make meaning in science education undergoing a shift due to the growth of digital media?

Henry opined that you can create an embodied interaction-based exhibit where learners play a game like virtual basketball, but it would be a mistake to replace the physical object with a virtual one. While they are not focusing on embodied human-computer interaction, Wood and Latham (2011) emphasize the role that embodied engagement with physical artifacts can play in the meaning-making process, arguing for a phenomenological approach to touch in a museum setting. “One of the familiar tropes of touch is a person reaching out to feel (with the hand) an object to determine if it is ‘real,’” they write. Visitors may do this to verify, to prove, or to reassure oneself that the object is what the eyes perceive it to be. Haptic and tactual feedback may provide rich op-

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14See especially Law (2004, Chap. 3) for more on this subject.
portunities for meaningful interactions in these settings. Larssen et al. (2007, p. 275) note, of interactions with tangible objects taking place *within bodily reach*, an important characterization that denotes those “taking place on, near or fairly close to the body,” examples could include wearables that respond to weight or pressure placed on body, or moving tagged objects in an augmented reality environment.

Furthermore, making the simulation, constructing it and understanding its parameters in a world of pixels, can be highly evocative. The act of being involved in the construction or making of a learning object, according to Ella, especially at the level of watching a virtual object become material or vice versa (as you see with 3D printing), may slow the process enough for learning to happen, for the bridge between abstract and concrete to be connected.

Blurring the lines between material and virtual interaction can be powerful at other levels than just embodied engagement or involvement in the construction of virtual objects. Virtual media can occasionally challenge temporal constraints and enable content that spans geography and history, for example. Jocelyne noted, regarding the collaborative digital media project that she has been involved with for the past year:

> when it came along, there was an opportunity to have students engaging with parts of nature that there’s no way they could naturally really see - bugs laying eggs, for example, or a complete life cycle, or the way that slight changes in habitat would completely alter the life cycle and even existence of some species. I loved that it was based on the same premise that kids have to have experience with nature and science for it to be real and for them to really care about it. I think it’s important to have both [material and virtual], because the kids are great with technology, but there’s still this novelty to using it like that. I think it’s important to have a real representation at some point in the study as well, so it doesn’t feel like a video game, which is one of the only things they’ve been exposed to that will usually look like that virtual representation.
This does not preclude students being able to understand, or even experience, organism life cycles without the aid of virtual media, but it would be challenging to represent something like biological adaptation in the manner that she is suggesting. Of course, adaptation could be taught using images in a text book, but a case could be made that the novelty of an adaptation occurring over millennia presented as an animation on a tablet device could be particularly compelling.

So the value of virtual media as an enhancement to traditional media and tools, I think, is well supported here, but Jocelyne, one of the teachers who has had a chance to evaluate how it fits in her own teaching, cautions not to become overly dependent on it for a simple reason: that “there are times when a pencil and paper really do the trick, and might actually be better in that moment than the most beautifully planned piece of technology, because a student is stuck, and they need to see it the way that they already are familiar with.”

Donald offered an interesting example alongside Henry’s previous one with the basketball, a more intimate, holistic, and phenomenological one:

*I don’t think that virtual representations should ultimately substitute for the real experience. I’ve got quite a lot of examples of this in the museum world. For instance, there’s nothing like seeing the Mona Lisa in person, as opposed to online. It’s a completely different experience. Or seeing and being able to touch a piece of moon rock for the first time... that’s a completely different experience than seeing a picture in a book, or something online. Or even to be able to rotate an artifact in a virtual environment to see it from all kinds of angles is a decidedly different experience than actually being able to see it rotate in real life. Being able to see wires jump when you move a magnetic field close to it, that’s a pretty... it’s a phenomena, a real experience, and you can talk about the ways that forces impinge on current carrying wires and the presence of magnetic fields as much as you like, and do simulations on*
them as much as you like, but when you actually see the thing happen, that’s a different kind of experience! So I definitely lean to the notion of supporting as opposed to replacing.

Seeing the Mona Lisa or touching a piece of moon rock can be profoundly more moving than swapping a pencil and paper for an interactive white board, though. Being able to say that you’ve seen the Mona Lisa can have a social currency attached to it. That said, is there space for what Latham (2007, p. 248) deems “numinous” museum experiences, those “deeply felt, connective encounter[s] with any object - not just artistic works or beautiful things” that can happen anywhere and anytime, in the space of science museum interactions? Do young learners have these lasting and meaningful experiences when they see a generic steam engine for the first time and really understand what processes are in play? Does interaction with the virtual enhance or complicate this?

Mike, commenting about an AR application developed for a science centre that featured animated 3D birds rendered on mobile devices, offered the following about screen-based virtual representations:

*I feel like most people, especially a lot of young people, are probably comfortable with that marriage of the physical world and the virtual world and the crossover between them. I think the one thing that can’t be discounted, however, is that the tactile element, perhaps right now, isn’t being as heavily highlighted. There are a lot of museums that are talking about screen-based experiences, but there’ll be a lot of kids walking around and saying “look... there’s a bird on my screen” but no, the bird is supposed to be right there in front of you! I don’t necessarily think that this is an issue with the technology so much as it’s a design issue.*

How fitting is Woolgar’s (2002) suggestion, then, that virtual technologies should “supplement rather than substitute” in light of these comments? By what scale can
the so-called “realness” of an object be determined, and along which axes should said object be positioned in relation to the environments and cultures it is derived in? As virtual environments become increasingly immersive, pervasive, and continuous, how is the boundary between supplementation and substitution blurred? The tactile element that Mike draws attention to is a crucial part of this equation. If a simulation is going to be perceived as a realistic, or at least semi-realistic, stand-in, its success may very well hinge on how well it can activate more than just the visual sensory system. Why didn’t the birds in question seem realistic to him? Perhaps they were too small. Or, perhaps their animated flight pattern didn’t mirror that of their real-world cousins. But what if some sort of haptic feedback was included in the application, so that the device would vibrate, for example, when a bird flew into the viewfinder? This is the sort of promising direction that researchers at Disney are moving in with their Revel framework (described in Chapter 2).

5.3.6 Social Media - Social Collaboration

I expected that a number of the interviewees might comment on the role of social media in their digital media engagements. Surprisingly, this topic came up rarely. (Although Pam did briefly mention an art museum project she was involved in designing that asked students to use different social media platforms to discuss content in the museum.) Jocelyne was one of the few, as she echoed the concerns of administrators and parents at her institution, that students might be tempted to use social media in class if given the opportunity. Maya, however, noted that in her estimation, “what is going to make the student, instead of wanting to go to Facebook, want to go on these other more educational things, is to really engage them at both the curriculum and technological levels.” Russo et al. (2009) posit that social networking can be a crucial element toward new media learning in museum-based informal learning engagements, precisely because it enables increased learner agency. Crucial to my position that narrative-focused learning can be
enhanced by digital media, and take a central position, in these sort of engagements, Russo et al. (2009, pp. 164-165) suggest that by implementing social media into informal learning, “collaborations between cultural and educational institutions could focus on storytelling, culture and education, and be centred around particular topics or questions which evolve organically, enabling new knowledge to emerge from the engagement of young people.”

Wyman et al. (2011, p. 462) suggests that “if a museum embraces the idea of interactions between curators and visitors in the public space, then it is relatively straightforward to implement a social media presence and, more importantly, to sustain the effort.” With this in mind, perhaps even more surprising was that I expected there to be plenty of discussion about the role of social media in enabling user-generated content, especially in science centres (and museums more generally), but I was surprised, again, to find that this wasn’t a topic that, in general, respondents were thinking about (or expressing). What did come up frequently, though, was the capacity that personal devices have toward fostering - as well as inhibiting - collaborative social engagement. New types of hardware, especially more embodied things like glasses or earbuds, present unique opportunities and problems. Tim, in the particular context he generally works in, with elementary school education, noted that “things are so social. You have no privacy in elementary school. Everything is just out there, and most activity is really as a group. For that age group, I think that that social context is really critical and unavoidable.” He went on to state that “the kids enjoy the opportunity to be physical in a gross motor physical way. To move around the room. To get up and change position and change location within the classroom. They just have a lot of energy. They like to move. It gives them some opportunity to socialize.” Regarding the Google Glass project, he offered that “one disadvantage I could see is the lack of a social context in considering an interaction with whatever the content is.”

Donald commented that he could
Chapter 5. Analysis of Interview Data

... easily see a scenario in terms of the digital technologies with which many kids are very, very fluent, where that kind of opportunity to mediate experiences through their culturally relevant world would appear. If you think about the ways that students these days mediate their understanding, many urban kids are incredibly tech-savvy. They thrive on the social mediation of learning. So, if we’re thinking about how we can mediate the experience socially, collectively, collaboratively, using these kinds of technologies, and using their local environment - that is, their worlds - I can only see it as a positive.

Henry, however, reminded that enabling youth to learn socially in informal contexts is actually quite a bit more complex than it appears.

Young people are more conservative than older people, not less. I think that they are more and more willing to accept their peer group’s perspective or point of view, tend to be fairly phenomenalistic, and tend to reject concepts which require a bit of understanding. Even for the people living in apparently a non-physical world - cyberspace - I don’t think that world is particularly novel. For one thing, it’s contiguous; It believes in a contiguity of form. It’s been a hundred years since quantum mechanics came along, and they still don’t grasp even the first understanding of that non-contiguous environment that our physical world represents that we fail to see. Young people are particularly prone to that. Whereas, as you get older, you can begin to accept many different perspectives. It’s very hard to do that when you’re young.

5.3.7 Gaming and Gamification

Similar to the lack of social media discussion, I was somewhat surprised that discussions about gaming and gamification did not frequently arise in these interviews. Would making AR more game-oriented, especially if we’re talking about more serious, educa-
tional games, detract form its spectacular value? More important, would diminishing the element of playfulness in this context, something that is crucial for science centres, institutionalize the activity in a way that might run counter to the learning objectives underlying the game? Grimes and Feenberg (2009) have drawn connections between some of these questions and the more widespread rationalization of play. Ueli commented on introducing gamification elements, like badges, in exhibits, offering the following thoughts when asked about whether his group engages in developing experiences that are gamelike:

_There’s a very context-dependent answer. We haven’t really been engaged in developing for gaming, so far, but what we do experience when talking to museum people is that they are quite interested in the gaming aspect of digital media. For instance, in an energy exhibit we developed, they wanted an energy game where kids could participate using an iPod or similar device. But, you know, that’s a natural thing for a museum space, because you have so little time to convey what you are interested in conveying. With regard to badges, they can go both along with more of a game-y genre, or along with more of a challenge genre. Kids can earn these badges with their understanding of a particular theme, for instance, which isn’t really that game-like maybe, so it really all depends on the driving forces behind your engagement, and whether kids are playing with something or someone, or whether it’s the content of the museum that provokes the imagination or curiosity._

5.4 Shifts and Tensions

A number of direct tensions emerged from a few of the interviews, spanning domains and subjects. Because the identities of the interview participants were anonymized, they were free to speak critically about their institutions, partners, and fields, as well as to give honest forecasts about what these kinds of technologies might afford. Furthermore,
participants were free to carry our discussions into negative, critical, and even dystopian territory at any time.

### 5.4.1 Design Considerations

Not engaging in digital media development practices that, in the words of Maya, feel like “a sticky note on top of your curriculum” was a concern for nearly every person I spoke with. It’s deeper than that, though. Not letting the technology get in the way of the qualities of the space is something that I’ve already touched on, but not getting away from a phenomenologically-driven museum experience, Ueli suggested, is important “if you want to convey what we call the non-tangibles - the skills, the material properties, the craftsmanship - of whatever goes into these old objects. It brings an authenticity to the whole experience, which makes you remember it in a sustaining way, or makes you more curious, or makes you want to explore more.”

Significantly different spatial considerations will likely impact how AR is designed for open, free-flowing science centres relative to bounded classrooms, but should they? Can collaborative classrooms feature AR (and other digital media) experiences that use a gesture-based approach to human-computer interaction? Tim hopes so. He noted: “I still kind of like to type. It’s efficient! But I’d like to just be able to wave my fingers in the air, or type them on a piece of wood, and have it be reliable. That said, reliability is pretty critical for me.” And there’s the rub. If designers don’t realize that they need to deliver seamless, working experiences, they will run into resistance outside of experimental testing environments. Furthermore, there needs to be adequate training into understanding how to move within the new technological paradigm once it has been introduced. That said, when dealing with pre-release applications, prototypes, and anything more beta and experimental, there is leeway to find success incrementally. Ben summarized this thought succinctly: “Well, when it’s bleeding edge, even partial success is great success!” That said, while this leeway might be applicable in an experimental
or design context, it doesn’t necessarily extend when applications are required to be made public. A string of partial successes could spell disaster for public institutions like science centres or museums. Even classrooms outside of an experimental or research context might not be particularly forgiving when it comes to time wasted by teachers trying to make an application work as opposed to delivering tested curriculum content.

Mike made a point around the sorts of questions that arose after his group finished a major re-design of a science centre to feature more interactive and immersive free-moving experiences: “People who want to go into a museum, read a bunch of panels, have a couple of activities, and come out and go ‘whoo... now I understand some science’ have been a little critical of the way that this space was set up, frequently saying ‘what am I supposed to be doing here?’” In this particular context, they designed the space without a lot of instructional objects, but as people come through and the science centre is able to do visitor studies around how they’re using the exhibits, they’ve had an opportunity to add instructional content wherever necessary. This proactive approach is an interesting one, and could be adopted with the introduction of gestural based or interactive exhibits, as well as AR-enabled exhibits that only respond when triggered by a sensing device of some sort. “It seems to me that it would be much harder to take away than it would be to add in after the fact” Mike added. “But there are people who just want to go in and go to each station and say ‘tell me what I’m supposed to do here... huh, I’m supposed to do this here? Watch this video? Ok, I’ll sit down and I’ll watch the video.’ They come out and they go ‘we did this, we did this, and we did that... we’ve had our experience.’”

Falk (2006) suggests that focusing upon the inter-connections between visitors identity, motivations, and learning is a crucial part of enhancing our understanding of these kinds of experiences, but being aware of the myriad reasons for visits - “social and recreational; educational and self-fulfilling; cultural in small and large ways; evocative of awe and reverence; and restorative” - as well as the fact that visitors come into the space with well-formed opinions and knowledge, is critical. Falk (2004, p. 92) makes the case that,
due to these sorts of factors, we now need to “design our investigations with a new level of sophistication in order to accommodate the true complexity of learning from museums.”

Kitalong et al. (2009, pp. 144-146) recommend an approach termed “narrative mapping” that encourages conceptualizing and representing the relationships between the rich variety of interactions, the physical space itself, and the users’ ways of navigating and conceptualizing the space. They recommend that designers and usability testers in museums and similar spaces should “look beyond the screen to devise new ways of developing and evaluating multimodal and three-dimensional texts.” Their study applied a retroactive narrative mapping perspective to a mixed reality exhibit, and their design recommendations include being aware of different group sizes that use anchor or reference points in the space. While they were looking at kiosks, this is an interesting point to consider in light of the ROM’s Ultimate Dinosaurs exhibit (described in Chapter 2). Are there line-ups at the kiosk (or, in the ROM case, the iPad station)? Do users have ample time to seek and find technical help with the technology? Do they jostle for position? Employing reflexive design practices with regard to these complicated relationships between space, technology, variable user groups, and tangible artifacts is critical.

5.4.2 Groups, Institutions, and the Public

Connected to the earlier theme of collaborative social learning, designers, educators, and content creators must reconsider conceptions of the groups they engage with, from classes of students to families. The importance of family groups in science centre visits came up a few times, with both Henry and Donald commenting on the changing nature of the family group, each suggesting that it is fallacious to base design practices on traditional conceptions of family. Today, children go to science centres with grandparents, babysitters, and extended family members. Henry pointed out that

*we’re currently examining the meaning of the family. When you’re looking at a kind of group dynamic or social experience all the time, people go in social*
groupings, but they bring themselves. I like to say that they’re not searching for knowledge, they’re searching for affirmation of their personal identity. They care about who they are. Like, there are “owl people,” people who love anything to do with owls, where they’ll just gravitate toward that particular theme, and they’ll find that owls are something that they really vibrate around. When you’re in a group, it’s just doubly reinforced. Increasingly, because the science centre appeals to a very diverse audience, when you start looking at the groupings of people that come through in these so-called families, whatever they may be, families from different places in the world will come to a place like this with different members of the family. Although maybe 40 years ago, we had more of a European base, the science centre in particular is a very broad diverse spectrum, and visitors now bring aunts and uncles and grandparents with them. What occurs to us is that we have to have what we call layered experiences.

But Maya, on the school front, offered a counterpoint, suggesting that closer, more nuclear family relations, need to be involved in filling the learning gaps, especially around providing and teaching children how to use technology that can enhance their learning.

It’s not just the size and shape of the groups that learn within them, but the shifting boundaries of the institution that need to be reconceptualized. The size of an institution can play a considerable role in how the public interacts with it and assumes a sense of responsibility for it. Ueli, after noting the challenge in developing technology platforms that are extensible between large and small institutions, highlighted the trend of museum collaboration on databases, access layers, and middleware. But he also added that “a lot of interest in my country regarding museums comes from these smaller museums where you have a very strong ownership and community building around them. These community-minded people really take care of these smaller museums, while the big ones are not as supported by an organic community as the smaller ones.”
of informal learning is to be contiguous between large and small museums, as well as other cultural and learning institutions, then contributing to a sense of public ownership and engagement, possibly through things like enabling user-generated content, as well as highlighting why the public visits institutions like science centres in the first place, will play a considerable role in how museums continue to define their relevance in a world where they may have to compete with more disposable, cheap, or easily accessible entertainment and learning content. Mike drummed this point home, suggesting that “the number of apps that are educational being developed on iPad, all of that is just gonna make it harder and harder for museums to compete with how fast that stuff can be developed. The idea of the artifact or the physical spectacle is going to be quite essential to why people will come and visit.” This statement doesn’t necessarily suggest that iPads or similar devices are disposable, cheap, or easily accessible, but their growing ubiquity cannot be underestimated. It is also not to suggest that museums and similar institutions shouldn’t strive for disposable, cheap, or easily accessible entertainment or content, but that there is a likelihood that this sort of competition between home-based content and public content may be heightened by the availability of these devices.

This question of relevance came up more than once among different interviewees, and it was frequently bookended with concerns about user-generated content or spectacle. Charlotte commented about her institution’s willingness to engage public participation with their content via mobile devices and user-generated content, noting:

*One of things that is part of our mission, maybe not our mission per se, but our strategic plan for the next sort-of 3-5 years, is to be relevant to our visitors, and to be relevant, to matter, we have to be pursuing those avenues, because that’s what people do. That’s what our audiences are doing. We’d be sticking our heads in the sand if we didn’t embrace this technology and these devices.*
5.4.3 Which Way Forward?

As my interviewees have made clear, students are already burdened in classrooms by the pressures of assessment, by expanding curriculum, and by a need to understand technology that changes at a rapid pace. Is there a threshold at which point educators and developers need to go back and say “we’ve introduced enough digital... it’s time to re-emphasize the material?” Should we tiptoe or run toward an augmented world, and should we be highly sensitive toward over-stimulation in educational environments? Pam, who despite being a museum researcher also actively involved in the design of technology-enhance museum exhibits, expressed strong concern over how disruptive virtual content could be to established museum environments, echoing similar comments from Ueli that I’ve already pointed out. “if you’re introducing virtual representations or augmented models or simulations - and I guess that’s part of the problem, that you can do so much, so how do you know what the right approach is - there’s this problem of information overload, of taking away from the experience of actually being in the space and what you get out of the space.”

Nathan pontificated about a truly dystopian future, referencing both Stephenson’s “Snow Crash” *(Stephenson, 2000)* and the fiction of Philip K. Dick.

*This is what I want to talk about, where AR becomes like a liminal space. Flash forward 20 years, and let’s pretend that the world of machine intelligence and full-on robotic agency has materialized. That’s another world. The way we think of AR as our window or our lens, it doesn’t go far enough in that type of world. We’ve opened up a window, but what I think is really happening is we’ve opened up a small fissure in the dam. But the reservoir isn’t full. And we peer through and see there’s water, which is information, over there. But in 20 years, that dam will be overflowing.*

He turned this dystopian world on its head near the end of our interview, though:
With the shaping of a digital world that knows all about us, you get identity reinforcement and an echo chamber, and you only get feedback about things you want. I would assert that we are increasingly being monitored and having information about our habits reported to entities beyond our control. I would further assert that advertisers and political interests are well aware of this, and seem to be doing whatever they can to leverage this trend. This will make it very easy for us to aid those who want to manipulate us. In this world where new media literacy is required for learning, is there a way for a new media technology to get students away from whatever opinions they’re reinforcing in their own personal echo chambers? Some mechanism that forces them to see other opinions and perspectives? Let’s say the learner isn’t allowed to progress in a lesson or tutorial until they’ve properly considered other opinions, regardless of where they come from. I believe that we’re heading toward technology that enables myriad perspectives and untold ways of understanding.

Henry also picked up this torch, putting a utopian spin on how this kind of technology might be considered in learning spaces as it becomes more pervasive:

Could we imagine an experience where you’re very personally involved, and it’s not just something that senses your presence, but it responds to your mood, to your thoughts, becoming something that you effectively create? Could it be that the 3D objects in the space are shifting and changing and you’re having an experience that still feels totally real? Could that be an intellectual playground? Could that be a way for exploring mathematics? Places and artifacts that are physically impossible to create in the real world. Like 4D cubes. That would be something that I, as a museum administrator, would like to explore. I’d like us to imagine that we’re going down a fresh road. It’s not just a matter of finding new ways to use keyboards.
Chapter 6

Case Study - Floops

The interviews that form the bedrock of qualitative data collected for this research are enhanced by a short case study of my own experience with the design and development of an educational vision-based AR application for a local school. The development process is ongoing at the time of writing, but has given me better insight into how two quite different development communities - the educational software development community, and the augmented reality development community - operate in parallel.\footnote{Challenges associated with getting ethics approval from the University of Toronto, as well as the relevant school boards, in sufficient time to do collect data from the implementation of this application in the school made it untenable for this study.} This has given me a chance to explore and document the current state of vision-based AR from a user’s perspective, thinking about what elements of the technology I find useful and captivating, and how it is presented to me in a variety of formats and applications, as well as a more nuanced perspective as a developer, through which I interact with questions about user interface and user experience. As well, a number of the experiences and findings from the development process have had an impact on the direction of conversations with interviewees about current technological practices from a developer’s standpoint.\footnote{Further information about Floops as it is developed, along with code and documentation to run the app, will be updated on my personal wiki at \url{http://www.losingtime.ca/wiki/index.php/FLOOPS}} This gave me an opportunity to try out various AR tools, to experiment with techniques that
other developers were using, and to assess some of the merits and faults of this technology from a personal perspective.

Floops is an educational AR application prototype that I am currently in the process of developing for a biology class. Pursuant to an email request from a local secondary teacher who was looking for assistance in experimenting with new technologies for her grade 12 biology class, I contacted this teacher to suggest a simple prototype AR application based on the idea of illuminating the mechanism driving homeostatic feedback loops. It could be deployed on Android mobile or tablet devices. After giving a demonstration on 3D printing for the class (as the school had recently purchased a new 3D printer) we decided to explore how 3D-printed tangible objects could act as anchors for virtual content in this application.

For me, this has served as both an introduction to developing AR with tangible objects in mind, as well as thinking about encouraging student involvement in different stages of the design and development process. My original and continuing goal with this application, is for students to sketch out anatomical designs in easy-to-use 3D modelling software (Google Sketchup, for instance) that could then be printed on their 3D printer and used in the application. Engaging students in this process of imagining, designing, and rendering objects three-dimensionally could provoke discussions around what the size, shape, texture, or proximity between biological objects (like organs) means to the system that is under study. As well, it would hopefully lead to interesting discussions with the students about the materiality of virtual objects.

6.1 Design

I began the design process by thinking of the kinds of metaphors and tropes that might be fun, engaging, or interactive for the students. Early conceptual schemes centred
around modelling the experience along the lines of the electronic board game Operation\textsuperscript{3}, imagining students using a trackable backdrop mat featuring a human body that they would place 3D-printed organs on. When a particular pattern had been activated, an AR layer depicting an animated feedback loop would become available on their devices. After exploring a number of different hardware and software scenarios, along with the different development frameworks described in chapter 2 - and because I was already familiar with Android development and the Java programming language - I decided that Qualcomm’s Vuforia would be the most appropriate platform for this project. This partly had to do with wanting the extensibility of being able to use multiple trackable backgrounds, something Vuforia enables, so that I could begin with a stripped down skeletal layer (see Figure 6.1), and switch between muscular or epidermal layers along the way.

After downloading the Vuforia sample applications for native Android, modifying and compiling them, and then running them on a few different Android devices - a Motorola Xoom tablet running Android 4.1; an HTC Hero phone running Android 2.2; a Sony Xperia phone running Android 3.1; and a Samsung Galaxy Nexus phone running Android 4.1 - I was able to get a sense of how Vuforia responds on different versions of the operating system, different hardware, and, more importantly, different user interfaces. It turned out that the class had older Android phones running version 2.2 available to them, which created some limitations in terms of what the phones could do running the software, so I settled on developing for the Motorola Xoom tablets, knowing that I had access to a full set of the devices in order to run a full implementation in the classroom at some point. While this limits the long-term viability of the application unless the school is able to upgrade their devices, it ensures that the students are not constrained by limited technology or the poor user experience of a small screen. Ultimately, I have been driven by the goal of developing an application that can provide the teacher with

\textsuperscript{3}A description of Operation can be found on the Hasbro Games website at http://www.hasbro.com/games/en_US/operation/
a means of communicating a curriculum piece in a novel and interesting manner while, at the same time, enabling students to download the application and use it as a study enhancement in their own time.

Figure 6.1: A trackable image in Floops

A notable thing happened when I made the transition from developing in native Android (Java, XML, and C for the AR virtual content) to using the game development environment Unity 3D. Having already built a rudimentary native android application using the Vuforia framework in Eclipse, which is the de facto Java development environment, I elected to also try the Vuforia plugin for Unity 3D, a gaming engine and development environment that I had recently acquired a free Android plugin for Unity\textsuperscript{4}. I found the interface to be fairly intuitive and helpful, especially with regard to incorpo-

\textsuperscript{4}Unity 3D is a video game development engine that can be downloaded from here: http://unity3d.com/
rating 3D models and scripting animations. It dawned on me, though, that the significant number of developers working with AR whose work I had come across did so in Unity and, as a result, their applications were more often than not game-oriented. On the surface, this appears to be a case of the tool enforcing or reinforcing a specific use, but it’s deeper than that. I am not a gamer, nor am I a game designer, but I began to think like one when using Unity for this project, even as I would write scripts, an activity quite dissimilar from drawing game objects in a GUI-based editor. I started imagining AR layers that could be activated by buttons as different game levels. While I am not particularly familiar with game development, I found it fascinating that a simple design choice could have such a profound impact on what the content and user interface might look like.

I think the malleability of the format really led to this thinking. The gaming scholar, Jesper Juul, suggests that “of all cultural forms that project fictional worlds, the video game is a special form in which players can meaningfully engage with the game even while refusing to imagine the world that the game projects; the rules of a game are often sufficient to keep player’s interest (Juul, 2005, p. 200).” Imagining an application as game-like does not entail envisioning a fictional world, necessarily, but a balance between rules (in this case, software prompts to lead a user to switching between layers or different pieces of information), and the elements that could constitute a fictional world (representations, animated scenes, and possibly audio cues). Out of this realization, the subject of gamification in education came up, and became a topic of discussion in a few interviews (although it didn’t captivate interview participants in the way that other topics, like curriculum for example, did). Gamification is something that may well prove challenging for informal and formal AR developers alike as they try to navigate how playful and fun their applications should be. But the use of game engines to develop content like this may also prove challenging as educational software developers are forced to address theoretical subjects inherent to the medium that game developers are already
comfortable grappling with.

Because the application development didn’t start until near the end of the school term, an opportunity to run it in the class was not possible, but the teacher is interested in having it run in the Spring of 2013, when the curriculum module runs again, so the early conceptual model is currently undergoing modifications and further iterative prototype development stages in anticipation of completion for this later time frame. Beheshti et al. (2007) note the iterative process of designing virtual environments for educational purposes, suggesting that there are repeated stages of testing, modification, testing, modification, and so on. From my own experience, I’d have to agree. When doing experimental software design (especially with virtual technologies that can often, during the process, experience crucial updates to the development framework, or available hardware upgrades), the development process is less contingent on daily, weekly, or deadline-based deliverables. Testing frequently happens with groups of other developers, rather than in the classroom (or museum) where it would be considered a waste of time if it was not successful. With that in mind, additional prototype stages that I’ve explored have included designs based on using textbook pages as trackable backgrounds so that the text can be made interactive with augmented animations triggered by button presses to “enhance” the text material. As well, in an attempt to make the exercise more game-like and, perhaps, more interactive, I’ve started using abstract representations (in the form of 3D-printed shapes) to stand in for organs in a feedback loop. Only once a correct order of objects is placed on the backdrop will the feedback loop be activated. A process of deduction is used by the students to arrive at what organs the abstract representations correspond to.

As I continue to test and experiment, I will start to refine the experience. What I don’t want, is something like Letters Alive (described in Chapter 2), where any tangible artifacts incorporated in the exercise have little meaningful value (other than what they represent). The decision to use 3D printing and, hopefully, involve students in the design
process. This will satisfy three separate criteria that I think are all beneficial to designing a physical AR experience such as this: it will enhance learner agency by bringing students into not just the production process, but the discussion and design process as well; it will incorporate more than one form of media - in this case, tangible 3D-printed objects, as well as virtual content anchored to the tangibles; and, finally, there will be some sort of game-like (rule-based) mechanism for students to advance between different layers and interactions. This will be game-like in a loose sense, following the definition of games provided by Salen and Zimmerman (2003, chap. 7, p. 11) as systems in which players engage in an artificial conflict, defined by rules, that result in a quantifiable outcome. The quantifiable outcome will be the completion of a learning objective, while the conflict will be between the learners and the activity of solving the very simple puzzle set before them.

6.2 Critical Making

My design process has been influenced by a “critical making” approach. Ratto (2011) describes critical making as: “a desire to theoretically and pragmatically connect two modes of engagement with the world that are often held separate - critical thinking, typically understood as conceptually and linguistically based, and physical ‘making,’ goal-based material work.” It was through challenging the tropes and metaphors that frequently come up in digital media design, and thinking about how they are laden with meaning, that I was able to consider in greater depth how similar metaphors turn up in educational content, regardless of whether they are attached to digital objects or not.\(^5\) In science education, especially when approaching any subject dealing with human anatomy, creators must be careful to consider what sort of representations they use.

\(^5\)The “teapot” metaphor is an interesting one to consider. Chen (2004, p. 156) notes that in the early days of computer graphics, each new rendering algorithm had to pass the “teapot” test by rendering the famous Utah teapot data set, which eventually became a sort of “Hello World” of computer graphics. Vuforia continues this trend.
For example, my choice of a seemingly de-gendered skeleton, rather than an explicitly male or female representation of a body, was deliberate, and influenced by Haraway (1992, p. 324), who writes of the complexity of articulation, suggesting that both language and bodies are the effects of articulation. Nature is highly articulate, she argues. Nature articulates a gender for that skeleton, however, and just because the virtual representation is not endowed with the elements of a gendered body, that is not to suggest that it should be treated as somehow gender-free by those who interact with it. In fact, one of the critical questions that learners can explore through interaction with these kinds of representation is what, in fact, it means for an evocative object of science to have a gender, to be political. While there will not be space to design narrative content for this application, I am operating from the principle that AR is narrative-enabling, and believe that this sort of critical discussion process, supported by a progressive teacher, can foster a sort of collaborative narrative exercise in the activity, where students project their own identities onto the anatomical models, or formulate provocative ideas about the origin of the disembodied organs. It is through this imbrication of discussion, negotiation, enactment, and agency that the true goals of a critical making approach - to foster critical thinking through a process of physical making - can be realized.
Chapter 7

Findings

This chapter connects the interview data, literature, and development experience in light of the positions outlined in Chapter 1 as a way to reconcile my own discoveries with new issues raised during interviews and development. I highlight areas of both consensus and difference, and emphasize the relevance of this research for stakeholders.

7.1 Summary of Findings and Recommendations

Reiterating my points from section 5.1.3, that the emergence of AR is a complex process that requires a holistic stance to effectively study if we want to distill effective design practices and recommendations. Furthermore, it is a topical and relevant discussion that spans the education spectrum. Having attempted to take these things into consideration, I want to offer some recommendations derived from the analyzed interview data, as well as my own experiences:

- There are a wealth of freely available tools for development that someone with even a modicum of programming or design experience should be able to at least experiment with if they want to try out vision-based AR. In this sense, vision-based AR (and AR in general) is an accessible technology for development. Furthermore,
while these technologies are, for the most part, designed for mobile implementation, many are cross-platform, and can be used to develop for tablets, mobile handsets, and, in the near future, more embodied and wearable devices (like eyeglasses). This can increase the potential for developing transmedia content. This is important, because media convergence and transmedia storytelling will enhance the likelihood of successful AR adoption.

• As far as design is concerned, there are no real laws other than, I would argue, that context specificity is crucial. This poses a challenge for designing AR applications that can cross multiple contexts. Applications that bridge formal and informal science education are extraordinarily challenging to conceive, and even more challenging to build.

• There is no established AR canon based on a single or small number of disciplines, as there is with, say, gaming. AR researchers need to draw from computer science, human-computer interaction, digital media, learning sciences, museum studies, performance studies, information, and communications - not to mention the various humanities disciplines that increasingly interact with the technology, from history to anthropology.

• There are no specific sites or locations where AR is being implemented that afford the most optimal research opportunities, although museums, science centres, art galleries, and even commercial spaces that incorporate AR into advertising displays all provide interesting opportunities.

• AR as a learning tool is still in a fairly nascent stage of development, so no one group of educators appears to have a better handle on the technology than others.

• A host of educational considerations and criteria need to be accounted for before AR should undergo any kind of full-scale implementation, such as: how well it fits
with the curriculum; whether or not teachers and students have time to learn the technology as well as the medium; whether or not supplemental tangible materials and objects are available to support the digital content; and how well it takes into account spatial and contextual constraints. Recalling the recommendations from Kitalong et al. (2009) that were discussed in Chapter 5, it is critical, in a space like a science museum, to employ a structure akin to their narrative mapping technique that can integrate spatial and technical considerations along with questions about how different group sizes interact at stations, and whether there is adequate time and access for technical help. This will help designers effectively model the information or learning space in a way that reflexive changes can be implemented at all levels.

- Taking into account the availability of tangible materials and objects that can be interacted with, successful AR should be a support for - or an enhancement to - existing artifacts and environments, not a replacement. I echo Donald’s sentiment in this regard. While AR can potentially act as an affordable stand in for a variety of expensive and difficult to maintain artifacts, it remains a generally visual-perceptive medium (for the time being). In this sense, it is congruent with the “touch with the eyes” paradigm that is common in many museums. As more multi-sensory AR becomes available - particularly along the lines of Disney’s Revel (discussed in Chapter 2) - and things like haptic feedback from AR-enabled objects become accepted, a great deal of care will have to be directed toward imagining how something like touch can be better incorporated in technology-enhanced exhibits. Wood and Latham (2011, p. 12) call for using phenomenological touch to provide opportunities for visitors to “open avenues for greater access, appreciation, and awareness of the lifeworld through transactions with objects.” In the context of haptic feedback-enabled AR, this could extend those opportunities to interact not just with the materiality of objects, but with multiple layers of information that
could be associated with the object in a way that isn’t distracting or overwhelming.

• Further to the previous point, certain pieces of science curriculum may be more amenable to AR integration. For example, opening up “black boxes” or visualizing internal, atomic-level processes might be. Or the 4D cubes that Henry suggested. Could Nathan’s call for “some mechanism that forces [learners] to see other opinions and perspectives” - a sort-of negative or anti echo chamber - where AR meets serious games, for example, in something like an evolution/creationism showdown that lets kids see and interact with virtual representations from each perspective be the an appropriate use? These ideas would have to be designed with context-specificity as a primary concern. A science centre might be best suited to opening up the black boxes that they can support with existing material artifacts and exhibits. Some of these are naturally-occurring ideas, and some are even provocative. But recalling Ella’s comments from the previous chapter, teaching subtraction with a monkey and banana metaphor might not be.

• Along with this, while I am hesitant to favour specific scientific disciplines as natural homes for AR-enabled learning, I have seen interesting examples around biology and natural history. I suspect that, in the case of biology, this has to do with the uniquely enabling factor of embodiment that can make biology curriculum deeply personal (students can look inside their own bodies, in a sense, with this sort of technology). With regard to natural history, there is potential for a variety of well-placed factors, from narrative to spectacular objects of study, already woven into the fabric of many spaces where it is studied. In areas like physics or chemistry, AR opens up tremendous possibilities for animating life at the atomic scale that even things like microscopes, with their often monocular, directed view, would have trouble matching.

• Possibly more important, can AR in the interest of science education in a science
museum use the same metaphors and ideas as its formal counterpart? This is a crucial question that, any time discussion about bridging these worlds through technology comes up, needs to be asked. Rather than assuming technologies like AR will blur the boundaries between formal and informal science education, I think designers and content creators should be ready to accept that they may actually produce very divergent experiences, despite any collaborative design or development processes that are introduced to bring the two sides together. AR may actually enable learners to have far more rich and interactive experiences in science centres that can be complemented by starkly different, but equally effective, ones in classrooms.

- AR can be spectacular! It does not inherently detract from its educational or meaningful value if it’s flashy.

- AR has potential to make science education more engaging, but should not be introduced without caution. A number of the interview participants in this study, as well as some of the literature, remain overtly cautious for good reason. Related to this, developers should not neglect the design wishes of users. Involving them in the design process can provide a unique opportunity to explore questions around materiality and simulation.

### 7.2 The Potential Long-Term Viability of AR

Digital media developments for museums and classrooms are often considerably different, so can the long-term viability of AR as an educational tool be assessed from the research I’ve done? One area where vision-based AR thrives as an educational technology, I feel, is in its opportunity to borrow from more successful commercial and professional AR applications. With this potential growing commercial advertising market for AR, as well
useful application in fields such as biomedical communications\textsuperscript{1}, frameworks and toolkits will likely become more robust, with greater numbers of users contributing to them; 3D models will become even more widely available, both for pay and free; and a variety of corollary effects could go hand-in-hand, from YouTube tutorials to the emergence of AR development courses at universities, digital media college programs, and informal workshops.

Its success in learning environments may also be greatly influenced by the kind of hardware required to support it. Ben made an interesting point about using cheap, extensible, hackable computing platforms to deliver future AR content. “If not every student can afford a cellphone, what are we going to do? That’s sort of where something like the Raspberry Pi comes in, because if the computer itself is only $30, then the whole market segment of the sub $100 computer may explode in the next couple of years. Soon, there’s a pretty good chance that a $30 computer will be able to produce great AR experiences.”\textsuperscript{2} This opens up a number of possibilities. Chief among them is the possibility for a greater number of students to have devices that they can either take home, or be able to afford at home. Furthermore, the size and mobility of these kind of devices opens the door for integration with wearable electronics and computing devices. If, as I make a case for in the following chapter, AR can find a home in embodied interaction and wearable computing, then devices like the Raspberry Pi will be crucial for developers. Another important consideration, is that cheaper devices will also mean schools with limited budgets may not only be able to afford the technology, but will be able to replace it appropriately. Only a few years ago, I taught a digital presentation class

\textsuperscript{1}Ben described a use case for Layar Vision that can “recognize the packaging on medical materials and overlay an instructional video on top of it (which is essentially the kind of work being done in biomedical communications).” This is based on numerous commercial examples that have recently emerged, such as Digital Delta's Junaio-based work that can be seen here: \url{http://digitaldeltadesign.com/ar/ar-for-medical-facility/}.

\textsuperscript{2}The Raspberry Pi is a credit card-sized computer that runs a Linux operating system on an ARM chip, similar to an Android-based phone. It is designed to be extensible and hackable, and has captured the attention of hackers and developers alike. Its price, at around $30, was designed to make it affordable for creating applications for kids.
at a local elementary school. While the school didn’t seem poorly-funded, their computer lab was stocked with machines that were more than 5 years old, and ill-equipped to run the kinds of applications students requested. This consideration for procuring, as well as replacing technology extends to museums as well. Recall the quote from Barry et al. (2012) that I cited in Chapter 2, where they described an AR exhibit at the Natural History Museum in London, noting that the tablets and personal devices employed in the exhibit only 3 years prior were already well out of date.

Beyond these practical economic concerns, I believe that successful new media applications would benefit from providing some mechanism for users to communicate with each other, and not just the device or application and its scripted dialogue, especially in learning environments that value scaffolding, narrative-focused learning, collaborative social exchange, and peer-based learning. While this relates more to the immediate uptake of these technologies, their long-term success will depend on how well they can develop engaged user bases initially. Can users acquire identities within the applications we build which they can then use to enact narrative functions? These leave a hermeneutic mark, an inscription or imprint, a reminder that someone before has contributed to the expanding discourse. Augmented reality is especially well-suited to engaging narrative learning, especially because it may enable imagined or alternative histories. Furthermore, for a software application that relies on narrative (user-generated or not) to remain useful, its events have to be released in an ever-continuing present - although not necessarily linear - with an iterative scheme for pushing out updates. (Barry et al., 2012, p. 8) suggests the following:

> to be successful augmented reality activity has to be captivating enough for the visitor to mediate their experience through what is inevitably a rather inhibiting viewing interface... successful growth and deployment of augmented reality will depend on its realization in two key areas; for the AR to be seamlessly woven into the narrative experience and, as in any good story telling device,
Chapter 7. Findings

for its viewing interface to become a transparent layer between the object and the audiences imagination.

7.3 Bridging the Museum and School Experiences

To reiterate my point from earlier in this chapter, applications that bridge formal and informal science education are extraordinarily challenging to conceive and build. This has to do with a variety of factors, including different financial considerations, problems with software scalability, approaches to interaction that are context-dependent and highly contingent on demographic and user group considerations and, often, fundamentally divergent missions.

Price and Hein (1991, p. 505) note that “as school budgets have tightened during the past decade, school systems have increasingly looked for alternative sources of instruction. When spending limits force schools to cut positions for science specialists, increased use of the local science museum or science centre can make up for some of the losses.” While this comment seems to imply a mutually exclusive relationship between schools and science museums with regard to their curriculum and content, I believe there is considerable evidence that they are mutually beneficial. Phillips et al. (2007, p. 1490) have written about the long history between schools and informal science institutions connecting “through field trips and outreach programmes, and, more recently, teacher professional development programmes.” That said, there are challenges to creating bridges between them, especially when designing software, and often rightfully so.

Educational software applications tend to be more focused on multi-year scalability that spans location and other boundaries. They often tend to be all-purpose, and are built with generalizability in mind. Museum exhibit applications, on the other hand, do not tend to be re-usable, save for with regard to code re-use. While bigger exhibits that are not intended for a specific institution can be tailored to go on the road, most
museum exhibits built around digital media are not built with this in mind. Because of scalability, cost, and complexity of design (as well as a host of other issues), museums might be more capable of leveraging experimental design and content than classrooms, where teachers need to be involved in curriculum design and school boards often don’t have the money to spend on new technology. Ueli noted his preference for working with museums, stating that “I think museum spaces and museum people are kind of open to experimentation and new ways of looking at things, while school settings tend to be a little bit more restricted by institutional demands. It’s an infrastructure that is there, and both teachers and students know about this infrastructure.”

There is a delicate balance between leveraging these financial and spatial affordances toward truly meaningful engagements and generating the kind of spectacle that drives paying visitors through the doors. The trade-off might exist in striking an appropriate balance between material and virtual content, for example. It might have to do with more embodied, physical, and collaborative methods of engagement that schools simply cannot accommodate. The fact that, unless on a field trip, a child or teenager visiting a science museum isn’t really a student in their capacity as visitor should not be overlooked. That they will travel through the science museum from exhibit to exhibit, spending only a few minutes at a time at each one, is significantly different than the focused time they must spend interacting with learning objects in a classroom. How this movement is mediated within family groups, often with parents acting as de facto docents, also highlights this distinction. Falk and Dierking (2000, p. 123) note that “within the three-dimensional space of the museum, time, too, is an element of space” and Sandifer (1997) has studied the amount of time that family and non-family groups spend during both weekday and weekend visits, suggesting, among other things, that crowding during weekend visits has a significant impact on time spent at each exhibit as visitors intent on learning may feel pressure to move quickly.

Furthermore, understanding the different material considerations at play is critical
to addressing some of these questions. How can one design applications that interact with tangible objects when schools do not have the same tangible objects available that science museums do? de Freitas and Bentley (2012, p. 37), writing about math curriculum, suggest that “museum-based integrated learning experiences offer students an opportunity to grasp the materiality of mathematical entities, and that material encounters with mathematics can lead to new ways of thinking about discipline knowledge.” Recall Henry’s comments from the previous chapter, in which he stated that, as a science centre administrator, he would like to use technologies like AR for this: “Could that be a way for exploring mathematics? Places and artifacts that are physically impossible to create in the real world. Like 4D cubes...” Wood and Latham (2011, p. 10) write of “the phenomenological tenet of intentionality through which the museum visitor can bring a directed awareness toward the object and their interactions with that object. This allows for materiality to be brought to the forefront of object transactions, further supporting the inter-connected nature of the objects material, cultural, and personal meanings.” Until classrooms are fundamentally re-structured, this consideration will be hard to extend into that realm.

In science centres that foster creative collaboration and user-generated content by their visitors, what factors impede the development of exhibits that let kids build, take apart, or destroy objects or artifacts? Take some bizarre Rube Goldberg-y apparatus. What prevents kids from being able to spend a morning building components and connecting them? There is, of course, the fact that the experiments should probably end up working. Ueli notes that “talking with museum people, what they are very concerned about if they introduce such technologies, is that things should work, and they shouldn’t be half-done.” Snap-together, extensible electronic kits like littleBits\(^3\) or more sophisticated (and more expensive) items like Lego Mindstorms\(^4\) partly enable this, but it’s

\(^3\)http://littlebits.cc/

a bigger challenge when developers want to introduce digital content. What sociocultural and generational factors contribute to decisions to enable these more hands-on user experiences, and are they changing with the advent of more disposable digital tools?

**Donald** made an interesting point around designing demographic-appropriate hardware or engagements that I hadn’t considered outside of a museum context.

*The content that is delivered needs to be appropriate to the demographic that is experiencing it. Take age demographics, for example. The experience that a family group wants will vary depending on the presence of an adult couple, or a senior citizen, or a young child… it’s all totally contingent on this. How do you go about designing the interface so that it’s demographic-appropriate? There are a million combinations of visitor experiences and demographics. What’s your purpose for visiting? Do you really care about all of this information, or are you there for an aesthetic experience? Are you there for relaxation or restoration?*

When these considerations are applied in a human-computer interaction context, they elicit really fruitful and interesting questions that educational technology developers do not frequently have to do deal with. Topics that are particularly relevant, in addition to the ones raised here, have to do with the fact that children are more likely to touch and interact with hands-on exhibits (*Dierking and Falk, 1994, p. 68*); that a general understanding of sociocultural theory can be valuable to making sense of how the factors described above interrelate when trying to understand how visitors perceive their own family interactions, even when the concept of family can be nebulous or shifting (*Briseño-Garzon and Anderson, 2012*); and that, while distinctions between the kind and amount of learning have to be made between family visits and field trip visits can be made, as well as distinctions between the type of institution (science centre versus technical museum) or exhibit (permanent versus travelling), there is consistent evidence of learning across the spectrum (*Falk, 1999*), as well as evidence that visitors to science museums do, in fact,
learn science (Falk and Storksdieck, 2005), even though it can be challenging to ascertain what visitors learn from these educational experiences (Falk and Dierking, 2000) and (Pedretti, 2004) (although, as Falk (2004) suggests, it is necessary to situate learning from museums in an enlarged scale and scope if researchers are to validly determine what is and isn’t “learning”). Designing interactions, especially with embedded digital media, can be complicated by each of these considerations, as the boundaries of what constitutes a user group, something developers frequently like to clarify well in advance, are tough to demarcate in this context.

7.4 Narrative, Content, and Curriculum

If Nathan is right, and AR (and similar new media technologies that feature novel forms of human-computer interaction and transmedia capabilities) appear to facilitate narrative-driven learning, especially when the capability for novel content creation is built into an application, then this may, in turn, have the potential to up-end conventional top-down information transfer in favour of a more user-focused approach to interaction.

Jocelyne, when asked about whether virtual content should be more playful in order to inspire kids, expressed the following concerns:

This is a really tough question. We know what part of the problem is: every kid can be killed or kill something in a game, and they press reset and they start again. So, there’s a fleeting moment of caring about something, and there’s just this non-permanence to it all that doesn’t really seem real. I think something that could combat that a little bit, and this is a vague suggestion because it depends on what the simulation is, would be an opportunity for students to be involved in building whatever is being represented virtually. They would be involved in choosing which habitat it’s going to be, for example. Is it going to be in a temperate forest or a boreal forest, or will it be a desert
or a swamp? Then they choose what kind of aquatic life should be there, and they choose a variety of factors that help make it successful. I think that this would go a long way to making kids care, toward the experience feeling a little bit more like something that they own, rather than something that’s fleeting, although obviously that would be difficult in some situations. I think that investment of students being involved in design, being involved in the critical thinking of whether their idea is going to work or not, is so important for their long-term investment and motivation toward the project. It’s too easy sometimes with technology to, like, start again and start again, but investing the students in the design process would be ideal, because there is brainstorming, there is review, there is re-doing, and what they make can then be the foundation for further study.

Narine and Grimes (2009, p. 320), commenting on the rationalization of children’s play through “the idealization of purposive play, with its emphasis on outcomes and progress” suggest that “in the digital age, the same contradictory tendencies have resurfaced within discussions about childrens use of information and communication technologies.” While their focus is on children’s leisure time, the same concerns over making effective, educational - serious - use of digital media extend to educational environments.

Mike, speaking about user-generated content in a particular museum context, suggested: “One of the next things for us will be to make those kinds of experiences multimodal. Giving users the chance to capture something, or note something, and to attach that to the exhibit virtually. That is a whole other can of worms that museums are trying to tiptoe around: making sure that a museum is still a safe space for a parent to bring their kids, but also responding to the complete paradigm shift in the way social interaction takes place.”

He offered further comments on the subject of user-generated content and its relationship to relevance, something I addressed in the previous chapter, noting that:
I think that it’s gonna be something that the institution will come to rely on. To come back to this idea of visitors asking “why do I have to go here or why is this important when I can get everything on the internet?” The idea of forming a strong community around the institution, and one of the best ways to form a community is to not only inquire from the visitors about their experiences, but to re-incorporate those into the teaching and experience design. This way, they know that they’ve contributed, that this is now a place where they’ve shared stuff, and they should go back again and again, and not just visit it once a year, but continue to contribute to the changing ecosystem of the museum, year after year!

But this can be a double-edged sword. Stein (2012, p. 221) cautions that “some have speculated that by pursuing the mood and movement of the ‘crowd,’ museums may fall into a trap of simply trading one set of blinders for another. The danger that museums will inadvertently exchange their missions for one that is defined by popular opinion is an important component to the discussion.” This recalls the suggestion from Wyman et al. (2011) in the previous chapter that people still believe in the experts, but that the expert voice is now one amidst many clamouring to be heard in a media-saturated world.

Mike noted his preference for exhibits that foster creativity: “A really successful interactive experience is one where you don’t notice the technology at all. You walk right up to it, start having fun, and then maybe afterward you realize that there was a bunch of magic going on. The best experiences are ones that don’t seem to have anything to learn, necessarily, but those who are really interested will end up exploring the system when they understand what the boundaries are. That’s always the type of experience that I would push for, as opposed to one that relies on novelty or some type of new technology as being the thing that sells the content.”

How do “imagined” environments differ from informational or historical ones when it comes to delivery of unique, lasting, and evocative content? By imagined, I am referring
to environments that borrow from historical examples to create wholly new stories. For example, an imagined AR environment might be situated within an historical artifact—a fur-trading ship, for example—but rather than re-tell a documented historical narrative using material or virtual objects, an entirely new and invented script, informed by historical evidence, would be supported by the introduction of uniquely imagined virtual objects.

7.5 Future Scenarios and Technology Convergence

A number of the interview participants noted that technology wasn’t going to solve any problems they saw with education. “Technology should be a way to enhance the content, and not the other way around!” was a familiar refrain that I commented on earlier, resonating strongly with Buxton’s comments that I’ve referred to throughout. Pam suggested that “you need to have an understanding of how you think learning happens” adding that “between the technology, the user perspective, and an understanding, pedagogically, of what kind of interactions you’d want to support, there’s also this median content layer. That is where drawing on the experience of the curators is important.” She invoked Liestøl’s concept of “meaningware.” Liestøl et al. (2004, p. 389) suggests that:

the computer, in its various manifestations, has become a dominant tool for communication and the exchange of meaning. In addition to the traditional levels of hardware and software, we are now experiencing the emergence of meaningware. The production, dissemination, and consumption of meaningware, in all its genres and shades, from Web pages to computer games, now extends beyond the traditional catchment area of computer science and related disciplines and constitutes key subject matter for humanistic approaches to digital media.
Nathan noted something important about convergence that I think has to be taken into account. “It might be more important to stress this emerging, pervasive trend of digital convergence over any particular technology, because it is through that digital connective tissue of everything being rendered down into code or information that you gain the potential to add these augmented layers.” He later suggested that “It’s more important for teachers, or those who structure these learning experiences, to think not specifically about AR, but to accept some new realities that gathering information and formatting it in an extensible, shareable, malleable way is really the core driver of knowledge building for the future, and that’s what the digital content will thrive out of.”
Chapter 8

Future Work

This thesis has introduced original research about the role of computer vision-based augmented reality as an educational medium, a discussion that is topical and relevant in information studies, museum studies, learning sciences, and a number of other fields. It has made a theoretical commitment to addressing the ways that material and virtual objects come to interact meaningfully in a variety of learning environments. While I believe the findings outlined in this thesis to be of significant value to researchers in a number of different fields, I recognize limitations in the scope of this work, from the duration of my study to the sample size of my interview population. Testing the verifiability of some of these findings longitudinally will be challenging, but I’m going to offer some thoughts on how I (or others) might go about doing so. Anyone electing to do further research in the area of virtual-material transfer in educational digital media might be well-served to focus on one of the two worlds, formal or informal learning, more directly. Prior to undertaking this research, I was unclear of the extent to which development and content creation differs in the two arenas, but there are complex considerations that need to be taken into account for each field. While some researchers\(^1\) have attempted to find common ground between them, as I have done here, a longer-term,

\(^1\)See (Gerber et al., 2001) for example.
more phenomenologically-inspired study would likely require a situated focus.\footnote{See (Latham, 2007) for a phenomenologically-inspired study in museum space.} I believe there is room for plenty of interesting future research.

### 8.1 Ethnographic Approaches

Coleman’s survey of approaches to understanding digital media connects digital media to an academic sphere, ruminating on how to best study the impact of digital media interactions and augmented spaces within and between different academic disciplines (Coleman, 2010). She operates from the principle that to best grasp the broad significance of new and digital media, we should use various types of analysis, always paying attention to the contexts in which the media is experienced. Coleman suggests that long-term ethnography is an appropriate tool for teasing out the deep and rich variability of digital media in everyday life. Understanding the people and contexts associated with new media adoption, and not just the technologies and devices, is something developers as well as researchers should strive for.

Coleman (2010) writes about the imbricated relationship between culture and access, noting that researchers should pay heed to the multiplicity of protocols for organizing knowledge. Digital media is a \textit{lived} and experiential phenomenon, as disembodied as that experience often seems. Ethnography in both science centres and science classrooms, especially long-term, deeply-embedded study where the researcher has a chance to fit in to the environment, would be useful to evaluate some of the findings of this research, as it is specifically interested in digital media and the technologies that support it (which generally change at a fairly rapid pace, as do the skills and tactics of developers). A subject like cross-generational adoption of a technology like AR could be better understood through long-term study, especially with regard to changing attitudes among educators. Simply placing technology in the hands of users and watching how they interact with
it is not enough. Getting to know whether they are already familiar with the medium, what sort of assumptions influence their adoption of it, how they make it more personal, whether there are cultural or linguistic factors that help or hinder adoption of the technology (e.g. studying whether students whose first language is not the one being used to guide the learning have different degrees of interest or difficulty with the technology) - all of these are subjects that require a focused, in-depth analysis, that pays attention to social and cultural factors, something ethnography is appropriate for.

There are a number of interesting ways that ethnographic study could be designed to illuminate specific elements of the classroom-based findings from this research. To begin with, building on the work of Roschelle and others (Penuel et al., 2007; Roschelle and Penuel, 2006), an ethnographic study of the co-design process of an AR or mixed reality intervention in one or more classrooms could further illuminate whether there is a divide between how teachers and developers treat this technology as a useful learning tool.

Additionally, exploring different socioeconomic matrices by situating study in both public and private schools from across the economic divide could further illuminate whether there is a socioeconomic bias to adoption of this kind of technology or pedagogy. Recall Tim’s earlier comments about dealing with teachers at a private school who were well-versed in knowledge construction pedagogy. If this is a feature of public school education, an ethnographic study could help determine whether such teacher attitudes and pedagogical approaches are having a favourable or negative impact on learners’ ability to have meaningful engagements with this kind of technology.

Moving from an ethnographic investigation that operates from a broad visitor studies perspective in a science centre toward one that works more closely with a host of returning and less transient groups, from school field trips, to weekend workshop participants, to summer camp participants, a researcher would have an opportunity to assess changes in technology adoption over a fixed course of time. Falk (1999, p. 270), in describing a study of school field trips to science centres, writes that one of the findings was that students
exhibited knowledge that “was clearly constructed and developed from a rich variety of related learning experiences, including interacting with parents and other people in enrichment and extracurricular activities and in more informal interactions at home; reading books; watching television programs; playing with and disassembling electric and motor-driven toys; and participating in school and museum-based experiences.” Getting a handle on this rich sphere of interactions with people, institutions, materials, and technologies would only help push this sort of research in a thoughtful direction. In the case of the Ontario Science Centre, or a similar science centre that engages the secondary school students who study there in the role of “junior staff scientist,” studying these students as they both learn about the content, possibly develop it, and communicate it to the public, their families, and their peers, would be particularly revelatory.

Also, moving beyond science centres to other museums where science content frequently comes into play, from historical and cultural museums that exhibit the tools of scientific revolution, to art museums where learners can gain knowledge about material or visual culture, to folk museums where visitors might gain a broader understanding of a specific scientific practice, an ethnographic study might offer a chance to see how learners treat the subject of scientific knowledge and how we construct it, how it is enhanced by interactions with different disciplinary subjects. Of course, this still places science content at the focus, but some of these findings can be measured across a wide spectrum of content. Furthermore, I want to challenge the notion that we must look first within contemporary new media theory to understand new media. Fundamentally, the subjects I am interested in exploring are closely linked to the semiotic domain.

## 8.2 Culture and Socioeconomics

What sort of collective cultural bias may be produced by developers of AR technologies coming from European or North American backgrounds relative to those coming from
growing software development hubs like China and India? While Tim made an interesting point in my interview with him that "American science museums tend to be about big picture science," Donald commented at length on the phenomenon of science museum development in China and Southeast Asia that has run parallel to rapid economic growth. “This comes with the availability of money for developing cultural institutions, and with that a notion of status - ‘we’ve arrived... and look at our big museums!’ - and if you look across China at the moment, there’s an absolute explosion of palatial and grand cultural institutions, and among these the science centres are quite prominent.” He lamented that “they’re palatial, grand, huge, magnificent, but the people behind them don’t have, as a generalization, much idea about how these institutions service the communities and societies in which they are embedded. So, this makes linkages between the school and the science museum very tenuous. It’s not part of their tradition for schools to use science centres in the way that we might think about them in Canada, or the US, or Australia, or other places. The models that they are using are predominantly reward models - at the end of the term let’s go to the science centre for fun - as opposed to linking with the curriculum, and they haven’t done much thinking about how the science centre can support the community.” He goes on to note similar developments in India and suggests that Southeast Asia is poised to be a hotbed of this sort of development over the coming decade, identifying Laos, Cambodia, and Vietnam as likely candidates. Identifying a proposed science centre development in one of these countries and engaging in a long-term study of its planning and implementation in order to study whether these sorts of trends - palatial, grand buildings without strong connection to their local communities - could be rewarding if such a site were to focus primarily on digital media development, or rely on it for showcase pieces. That said, such research would greatly benefit from local researchers, who understand both the cultural and linguistic mores that contribute to the nuanced visitor experience. Briseño-Garzon and Anderson (2012), have written about the need for Latin American researchers to conduct similar localized research with
respect to how visitors interact with science museums in Latin American countries. The same recommendation could be made for research in the countries Donald alludes to here. At the very least, research conducted collaboratively from cross-cultural teams to compare findings between, say, North American institutions and Asian ones with respect to these new developments would be worthwhile.

Who makes up the development communities of popular frameworks? Are they teams? Single experimental developers? Game and entertainment companies? Marketing firms? How will cultural, managerial, and competitive factors of developing with this technology in techno economies like India or China impact development in emerging information technology hotbeds like Kenya, where mobile software development is a focus? D’Mello and Eriksen (2010), Deshpande et al. (2010), and Gregory et al. (2009) all describe the explosion of software development industries in India and China. What role will developers in those countries - and, more importantly, what role with their cultural backgrounds have - in the linking of AR and educational technology there, as well as around the world? These questions, prompted by increasing globalization of information technology, are necessary.

Related, we might ask how adoption of AR for pedagogical (and similar purposes) may widen a growing technological gap? Stein (2012, p. 223) notes: “Those on the less fortunate side of that gap lag in their ability to benefit from the ideas and creativity presented online, but also to contribute to the sharing and creation of an emerging participatory culture. As museums lean more and more on digital media to tell the stories of culture and artistic expression, a failure to adequately address barriers to access only contributes to a widening gap in participation resulting in the exclusion of these communities and their ideas from the ongoing discussion about culture.” Conversely, can it help shrink this gap? Under what circumstances? How are digital objects monetized (and in some cases made unavailable due to this process)?

In my interview with her, Ella described working with computer science students
who would come in to her class and “be like ‘oh, schools should be using technology, and teachers are not doing it right,’ and you’d walk into their classrooms and realize that they have 5 1990 Mac things in the corner that barely work. That’s the technology the school has, and all of us have to re-think our assumptions. It’s like ‘oh, hang on, teachers don’t use technology for reasons that are so much more complicated than they’re not smart enough or technically sophisticated enough.’”

Related to cost of technology, these socioeconomic considerations aren’t just about the amount of budget space available for new technology, they also have to do with the quality of teaching resources available. Tim, who works primarily with inner city schools in a large North American metropolitan area, after having worked on a project with a private school whose students come from predominantly affluent homes, noted that the private school teachers “were far more sophisticated than the teachers I usually work with in terms of having some kind of model of inquiry, a real dedication to inquiry, a sort of community knowledge construction pedagogy. They had a theoretical foundation that none of the teachers I’ve ever worked with here have ever really had.”

But increased funding doesn’t necessarily increase the educational value commensurate with new technological acquisitions. Ella suggested that “the amount of money that’s being spent on technology in this country is insane, with very little attention to what to do with it. With increasing money being spent on classrooms, I’m not sure that we’re any closer to doing what we should be doing with it. And I really don’t know if digital literacy is improving at the teacher level, or at the student level as a result.”

Undertaking a study to try to determine the value associated with increased expenditure on AR-enabled technologies, which are still relatively inexpensive compared to, say, interactive white boards, could, if designed to assess other socioeconomic factors, have measured value if it tied spending to outcomes in some way or another.
8.3 Other Media

While my specific technological engagement has focused mostly on mobile-based augmented reality, a number of other technologies - both software and hardware-related - might have traction. Among them, those that rely on AR-enabled embodied interaction might be particularly strong candidates for further study. How users inhabit the user interfaces they’ll encounter is likely going to be one of the biggest areas for future research as interfaces move off the screen and onto material spaces and objects. Google’s Project Glass, which is set to unveil AR-enabled glasses in the first quarter of 2013, will likely be at the forefront of this shift, as will innovations like SixthSense and other projects from groups like the Fluid Interfaces Group at MIT’s Media Lab, or in-eye/contact lens-based AR, like the ones that DARPA is currently researching.\(^3\)

Blair MacIntyre, who is an augmented reality researcher at Georgia Tech, has blogged about the unrealistic expectations that Google is setting the public up to have about this project.\(^4\)

The pioneering work of Steve Mann, which was the basis for Google Glass, takes augmented reality a step further. (Matsumoto et al. (2008) describe a design paradigm for linking web services through embodied interaction in an augmented reality context by augmenting a user’s experiences in the real world, for example, with access to infor-

\(^3\)More information on SixthSense, which uses a small, wearable projector to display usable interfaces that can be manipulated by gestures picked up by a wearable camera, can be found here: http://fluid.media.mit.edu/people/pranav/current/sixthsense.html. SixthSense, when it was first unveiled, caused a huge public splash - notably, when its inventor, Pranav Mistry, and his mentor, Pattie Maes, demoed it in a TED talk (which has subsequently garnered over 7 million views and is the 5th most-watched video in the entire series; Mistry’s earlier TED talk, which introduced the project, has nearly 10 million views, and is the 3rd most popular). It was the first opportunity for the public to see a wearable computing device that lets the wearer create a user interface practically anywhere in front of them, including on their own bodies. DARPA is the Defense Advanced Research Projects Agency, an agency within the United States Department of Defense that has a long history of funding these sorts of innovations. Some information about their research into contact lens-based AR for battlefield augmentation can be found here: http://news.cnet.com/8301-11386_3-57413673-76/pentagon-eyes-augmented-reality-displays/ Parviz (2009) provides some technical information on the how lens-based AR will work.

\(^4\)See http://ael.gatech.edu/blair/2012/04/05/185/
Information or social resources on the web on a customized mobile device. Their model uses a customized umbrella that projects information into its open canopy. Price and Rogers (2004) describe a more spatially-informed notion of AR-enabled embodied interaction that focuses on combining material artifacts, physical movement, and interaction with tools, that can be read alongside Manovich (2006). Work by Jimenez Pazmino and Lyons (2011), Lyons et al. (2012), and Malinverni et al. (2012) has carried this design perspective further into informal science learning, with a strong emphasis on effortful physical exertion in embodied interaction. Work by the former group includes a particularly interesting example where visitors to a zoo in Chicago are outfitted with wearable devices in the context of a game meant to simulate the experience of a polar bear swimming across a body of water with receding sea ice. The marriage of embodied interaction, gaming, and virtual simulation they describe is particularly resonant to me.

The emergence of gestural interfaces in learning environments also features prominently here, most notably around the experimental use of Microsoft Kinect in building interactive learning engagements. Ella noted that she thinks the performative aspect of
“the Kinect stuff in a multitouch classroom has potential because, by nature of what the kids are doing, their collaborative engagement means the teacher can’t always be in control,” noting also that she’d hate to see gestural interfaces employed in a laptop classroom because of the negative connotation she has toward kids staring at laptops, learning individually, with a “teacher masterminding the entire interaction.” She continued that “this is one of those balancing acts in classrooms that deals with how much control you give to the children, and I’m all in favour of giving a lot of it, but I know that teachers aren’t necessarily comfortable with that, and students aren’t necessarily comfortable with that.”

8.4 Studying AR as a Viable Learning Technology

With the spate free development frameworks competing with popular ones like Vuforia and Layar Vision, and, more important, the impending release of Google’s Glass project, a researcher might consider following the broader trajectory of this technology, especially with regard to its popularity among developers and the public’s adoption of it in mobile applications (and on other formats). There are a host of different ways to do this, but I would suggest that a more mixed methods study focusing on things like number of framework downloads, number of applications released using a particular framework, or demographics of specific demographic communities, could bear fruit.

In early 2012, Clark Dever, a popular photographer, wrote an “open letter to augmented reality” in the UK edition of Wired. In it, he wrote

To the decision-makers and venture capitalists in the audience, the market is speaking loud and clear. It’s time to step up your game. Fund the immersive, cloud-connected experiences that customers want. Use these new technologies

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5 Full text of this letter can be accessed here: http://www.wired.com/beyond_the_beyond/2011/08/augmented-reality-science-fiction-writer-becomes-augmented-reality-developer/
to show us real AR, banish gimmicks that only shine on the show floor, and please ground your flying logos. True AR is first person; no phones-as-looking-glasses, no laptop webcams. We want mobile, first-person AR, and we want it now!

Generational factors and new technology adoption rates are going to partly determine whether this technology takes hold of the public, first, before it can be sufficiently incorporated as an educational medium, but I agree with Dever’s assessment about true AR being a first person experience, about removing the encumbrances of mobile or tablet cameras. AR’s viability as a learning technology really hinges on the public’s willingness to embrace it, and that isn’t likely to happen if people have to walk around with phones in front of their faces. Styliani et al. (2009, p. 523), discussing the development of AR-enabled museum exhibits, suggest that “a major benefit of an AR-based interface resides in the fact that carefully designed applications can themselves provide novel and intuitive interaction without the need for expensive input devices.” My experience at the Royal Ontario Museum’s “Ultimate Dinosaurs: Giants from Gondwana” exhibit (described in Chapter 2) really speaks to the crucial role that embodied interaction can play in future museum-based AR development when educational considerations inform the content design. From the number of visits I paid to the exhibit, I noticed a general sentiment that visitors were collectively being wowed by the technology, but I didn’t notice much social or physical interaction, and I wonder how different it would be if, say, gestural control of the AR had been implemented (if even possible given the spatial constraints). Imagine groups of kids witnessing an allosaurus turning its virtual head toward them with jaws wide and eyes flared being able to repel it with a simple swipe in the air. This is simple, yes, in the sense that it’s not particularly sophisticated, but it’s also simple given that visitors are already using Kinect-based gestural swiping to control another digital media interface in the exhibit. Combining gestural with AR is one of a number of potentially interesting configurations that embodied interaction in these sorts of spaces will enable
in the coming years.
Chapter 9

Final Remarks

In my interview with Nathan, he made a statement that continues to resonate: “I think that the moment this becomes so pervasive that you don’t see it anymore, then we won’t call it AR. It’ll just be called ‘where’s my info?’” When I first began this research, a number of the developments that appear to be pushing the AR envelope did not exist, at least in the public record, from Google’s Project Glass to Disney’s Revel.\(^1\) Will these projects succeed or fail? They have successful backers with very deep pockets, but that doesn’t determine whether the public will embrace them. If pervasive AR is inevitable (and I’m not convinced that it is), can it be used in a practical, meaningful way that benefits its users, and not in the controlling, manipulative fashion that many dystopian visions of it foresee?

When my first child began to display signs of wonderment and curiosity, I, as a new parent, became equally curious about the internal mechanisms that were causing his little neurons to fire and his budding vocal cords to tremble and reverberate. Was it a fluid process, passing thoughts and new memories around in some viscous neural soup? Or, rather, a rigid, logical, distributed architecture, like a computer or piece of machinery.

\(^1\)Information about Disney’s experimental Revel project, which adds haptic and tactile sensory feedback to vision-based AR, can be found here: http://www.technologyreview.com/news/428736/disney-researchers-add-virtual-touch-to-the-real/
I saw him pinning objects and geometrical shapes to the anchors of his speech, and patterns began to emerge. I began to replace the objects with metaphors, and started constructing an abstract picture of how his brain was handling the most frequent or stimulating images, and how the context of his interactions with me was influencing this. One afternoon, while riding a streetcar up a hill, my toddler began gesticulating toward the sky and proclaiming excitedly “a ball! a ball!” Confused, I looked for a minute to find what he was referring to, only to realize that he had seen a full daytime moon before it went behind a cloud. Thus emerged the first metaphors that triggered my own curiosity toward the research I’ve been engaged in: the moon as a ball that floats gently across the sky as if filled with helium. Then, the moon as an eyeball, the foremost feature of an invisible face peering down at us from the heavens. Now, with our occasional use of mobile AR astronomy applications like Star Chart and Sky Map\textsuperscript{2}, the moon as an anchor for information, a pole star to a child’s eyes on the bounded screen of a mobile device, or the moon as a protagonist, some wise grey sage in a cosmic drama populated with dancing animals, vibrant planets, and dense bands of stars we can both imagine and occasionally see on a clear night. A few years after the initial streetcar ride that inspired all of this, while watching the Transit of Venus in a stadium with a few thousand other people, my child implored me to hurry up and put my eclipse glasses on and look up or I would miss this once-in-a-lifetime event. “Hurry up, Dad, because Venus is about to go in front of the Sun... and then it will go SMASH, right into the Sun, and then we will make our own new God.” I looked at him in shock at what he had just said, and he proclaimed to me, almost incredulously: “It’s metaphorical, Dad!”

I have two children now. The second was born a few months before I embarked on this project. As much as I have tried to be dispassionate about and detached from the

\textsuperscript{2}Star Chart can be found in the Google Play store for Android: \url{https://play.google.com/store/apps/details?id=com.escapistgames.starchart&hl=en}. Sky Map can also be found in the Google Play store: \url{https://play.google.com/store/apps/details?id=com.google.android.stardroid&hl=en}
theoretical material in this thesis, I must confess that it is a challenge to be. My kids inspire me to do this kind of work, because I am as hopeful about their educational futures as I am worried about them. Whether or not augmented reality or computer vision ever have the sort of impact on learning environments that I think they might, I have learned a tremendous amount about how my own children might interact with educational materials, both material and virtual, in their lives. I want them to look inside things, to understand how they work, to try to disassemble and re-imagine them, or attach their own stories to them. Like Feynman’s radios and locks, or Papert’s gears, I want them to be inspired by the form and function of everyday objects, to use them to abstract higher-level concepts. Digital media, at its best, enables this. It becomes far more than spectacle. Augmented reality is really an exemplary tool in this regard. It affords far more than just additional informational content. When done right, it is narrative-enabling, and it can really illuminate the inner workings of things - from bodies to machines to cultural and historical artifacts - and offer new representations to help our children (and their parents) make meaning of the world, in a way that other media before it have been unable to accomplish. Above all else, it can stimulate our imaginations.

\(^3\)See Feynman (1985), especially the first few chapters where he describes being inspired to understand how things work by taking radios apart as a kid and picking locks as an adult. Also, see Papert’s (1980) foreword to read his description about coming to understand mathematics and computing through a childhood interest in gears.
Bibliography


in an educational context. In The proceedings of the 35th Annual Conference Canadian Association for Information Science/L’Association canadienne des sciences de l’information, CAIS/ACSI, pages 10–12.


Appendix A

Legend

This thesis was formatted using the \LaTeX\ typesetting system and \BibTeX\ bibliography system. \BibTeX\ code for this thesis is available from me directly. While all of its content can be read on paper, it is optimized to be read as a digital file, as there are numerous links seeded throughout.

- Coloured links are clickable.

- The names of interview participants are clickable, and will return the reader to a short biographical description of the participant. The reader will want to make sure that the back and forward keys are enabled in the toolbar of their .pdf viewer in order to return to the page they were previously viewing.
Appendix B

Glossary and Terms

I make a concerted effort to use non-gendered language, to avoid capitalizing disciplines (unless they refer to a language group or geographical entity) or technologies that have a strong case for common rather than proper noun usage (including the internet), and to use Canadian English throughout this thesis. (My American readers should note that Canadian English uses “centre” and, as a result, I use the term science centre, regardless of an institution’s geographic location.) I also frequently use the first person to describe specific experiences, ruminations, and opinions.

While I attempt to avoid their use, there are frequent points throughout this thesis where terms with specific meaning in scholarly contexts are necessary. I include the following descriptions of terms that may be unclear, or have different meaning to a lay reader, along with references to further reading that may help clarify their meaning.

- New Media - Manovich (2002, chap. 1) writes of new media that it is made up of “graphics, moving images, sounds, shapes, spaces, and texts that have become computable; that is, they comprise simply another set of computer data.” Later, in the same text, he writes that all new media objects are composed of digital code and can be thought of, at their root, as numerical representations, although their presentation does not have to be in a digital format. They are modular, and their
modularity allows for the automation of operations involved in media creation, manipulation, and access. They are variable, and can exist in different versions across time and space. They can be translated into other formats and, as culture is computerized, a natural consequence is that cultural categories are substituted for ones that derive from a computer’s ontology, epistemology, and pragmatics.

- Digital Media - While often closely linked to new media in concept, digital media can be thought of more along the lines of media that is stored in a digital format. The emphasis on digital storage is especially crucial when taking into account the digital repositories of images and other virtual content that vision algorithms need to interact with to render AR scenes.

- Transmedia - This is a concept that frequently relates to narrative or storytelling as it happens across multiple formats or media using digital media technologies. Jenkins (2006, p.21) writes that “Transmedia storytelling is the art of world making. To fully experience any fictitious world, consumers must assume the role of hunters and gatherers, chasing down bits of story across media channels, comparing notes with each other via online discussion groups, and collaborating to ensure that everyone who invests time and effort will come away with a richer entertainment experience.”

- Bleeding Edge - The concept of bleeding edge technology is similar to that of cutting edge, except that it emphasizes the notion that new, untested technologies are often risky and can, as a result, perform poorly.
Appendix C

Interview Questions

As an opening strategy, each interview started with a question asking the subject to describe their experience as an educator or developer broadly. My intent was to give them an opportunity to tie their experience to their current research and, hopefully, tease out potentially interesting themes that could be probed at greater depth in the interview. For example, if they had experience working with virtual reality, but have moved into the area of augmented or mixed reality, I would later try to determine what caused them to make that sort of shift. While the interviews were conversational in tone, I used variations of the following sample questions to guide them at times:

- Describe your experience designing or developing educational content, in any context. Would you classify yourself as a developer, educator, or researcher? How would you describe your experience level?

- Describe any experience you’ve had with what might be considered “experimental” teaching tools or methods, such as interactive white board-based lessons, or the incorporation of mobile, handheld, tablet, or touchscreen surfaces into learning environments.

- Have you had any experience designing new media technologies? Do you have any
experience with mobile development in educational contexts?

- What are your thoughts on mobile or tablet-based approaches to have long-term potential? Would you consider them a fad?

- Do you have any experience with either locative or vision-based augmented reality?

- What are your thoughts on the viability of vision-based AR development in educational settings?

- Of the three prominent AR paradigms location-based; marker-based; vision-based do you feel that any of them will have particular traction over the others? In what ways?

- How did you feel your curriculum was enhanced by the incorporation of digital media? What do you think the students might have got from it? Did they appear engaged with the content, or wowed by the technology?

- Would you consider implementing similar projects involving augmented reality or other digital media tools in the future?

- In your experience, are museums or classrooms easier to develop for? Why do you think so?

- Do you think the physical/tangible/material experience can be replicated or simulated effectively with a virtual or semi-virtual one?

- Do you feel personal devices can be utilized in learning engagements that call for mobile or tablet technologies? What ways would you envision them being incorporated effectively?

- How do you feel user-generated content is changing the role of user agency in developing content for the specific formal/informal context you work in? What is the role of user-generated content in your institution or designs?
Appendix D

Illumine

Illumine is a conceptual model I am designing that will form a cornerstone of this research. Motivated by Kirschenbaum (2004), this is a prototype that will enable learners to use a mobile handset or tablet to register specific material technoscientific objects (computers; tablets; monitors) in their bounded environments and draw upon virtual content that highlights and illustrates internal components and necessary infrastructure of the artefact. The primary objective of this design is to teach concepts from physics (or another discipline) through this illustration process. For example, as students use their device to hover over where a heat sink on a laptop is physically situated, an augmented layer (agnostic to text, audio, or visual content) would materialize giving them information about heat sinks, such as why heat sinks are necessary and why materials like copper and aluminium are favoured, and then explain what this all means with regard to thermal transfer and conduction. The secondary objective is to enable learners to weave in their own narratives and author unique content. The end design will see them use the platform to build on pre-seeded information and instructional layers by adding their own videos, photos, and narrative content so that future iterations could build toward a collaborative knowledge community. While the example I’m working with is targeted toward physics curriculum, a similar platform could be used to teach chemistry, biology, or
a host of other subjects. Ultimately, I feel that this sort of research not only illuminates the interactions between learners as they explore the internal workings of what are, for many, technological black boxes, but may also provide a unique window into the agency of young learners as they engage with knowledge media.
Appendix E

Experiences

Leading up to, and throughout the course of doing this research, I have endeavoured to engage with both theory and practice equally. The following scholarly experiences need to be acknowledged for the influence they have had on this research. In an area such as this, attending conferences and similar events provides and opportunity to remain up-to-date with what is being developed and released.

• In 2011, as part of a graduate seminar course on knowledge media and learning, I collaborated with two other graduate students from the Ontario Institute for Studies in Education (OISE) to conceptualize a geographic information system that would enable children on long road trips to explore features of their surrounding landscape through specific, curriculum-based thematic lenses. The culmination of this project was an interactive AR-enabled touchscreen display that would be embedded in automobile windows. While this was specifically a locational AR tool, it was one of my first forays into thinking about augmented reality as a learning technology as well as playful and interactive media. I presented a poster on this conceptual model at the 2011 InPlay Conference in Toronto, ON, where I a number of other presenters described their explorations into using digital media - and AR - for educational purposes.
At the TIFF Nexus Locative Media Innovation Day (described briefly in the Literature Review chapter) in October, 2011, I attended a workshop given by Caitlin Fisher, the director of the Augmented Reality Lab at York University.\footnote{See \url{http://futurecinema.ca/arlab/}} While the workshop was a short, simple introduction to marker-based AR using an intuitive and easy-to-use interface that her group had developed, I was somewhat dismayed by the lack of creativity expressed by other workshop attendees, many of whom were designers and developers. While this is in no way representative, I noticed that the sorts of scenarios participants imagined - in my direct vicinity at least - mostly had to do with simple commercial application around placing markers in stores to generate text-based information about products.

In November, 2011, I attended the first of a series of workshops by the Ontario Augmented Reality Network. Held at Ryerson University, and featuring Lake Watkins of XMG Studio, a prominent AR game development group.\footnote{See \url{http://www.xmg.com/}} While the talk Watkins gave was interesting, again, I was somewhat dismayed by the lack of imagination displayed by some of the audience asking questions. While this likely had to do with the fact that he is a game developer, and a number of the audience members were gaming enthusiasts, the scenarios and examples expressed were mostly in line with first-person shooters, using mobile phones as AR guns to shoot virtual characters. During the question-and-answer period, though a notable exchange happened. Fisher, who I mentioned in the previous example, noted the potential of AR for developing long-term narratives. She went on to ask Watkins about AR development for, or with, women in mind (or taking into account gender considerations). In a somewhat awkward response, Watkins suggested that his group had developed “Style Studio,” a mobile application for playful fashion design. I thought this was a somewhat shallow response - I commented on it at greater length on
my personal website: http://losingtime.ca/research-blog/?p=84 - but this particular exchange raised concern about heteronormative and gender deterministic design practices in contemporary digital media development, and has had an influence on my own design practices since.

• At the 2012 iConference, held in Toronto, Kiersten Latham, as part of a panel titled “Material Relations: Information, Media, Technology,” gave a talk on using phenomenological approaches to gaining a deeper understanding of how the public interacts with, and learns from, museum artifacts (Keilty et al., 2012). She described studying tangible interactions that act as triggers, or links that spark thoughts, feelings, and evidence of the past. She identified proximity to the artifact as an important element, emphasizing the “need to touch it,” and noting that physicality matters in the materiality of the object. She went on to suggest that phenomenology is critical in information studies in that it digs into the rich, subjective experiences that museum goers experience, and that phenomenological methods emphasize that we need to listen to the user’s voice. Wood and Latham (2011) presents some of these ideas in greater detail, suggesting, for example, that: “Museums are places where, with a nod to Husserl, we go to see ‘the things themselves,’ where material culture and specimens from nature provide opportunities to help visitors see and understand the phenomena of the world. Museum visitors are able to get closer to objects that help them to understand the life world sometimes of the ordinary, sometimes extraordinary, but always within the context of relationships to people, places and time.”

• I attended a multi-day gathering of the Educoder organization in February, 2012. Educoder is an organization that brings together developers and researchers working in educational technology. There, I had a number of discussions with researchers and developers working with digital media in museums, including a handful who
have built AR and more immersive VR exhibits. I also had a chance to chat with a developer using a web-based platform to let students design 3D objects, print them, and construct engineering projects from the parts. This discussion influenced how I’ve come to explore incorporating 3D-printed objects into AR applications. At Educoder, I also had an initial chat with Ueli, who would become one of my interview subjects, about how his lab is building for a learning trajectory that extends between classroom and museum space into the interstices connecting them, helping shape one of the questions that was a cornerstone of my later interview process.
Figure E.1: A poster I presented at the 2011 InPlay Conference describing the ENroute project.
Appendix F

Consent
APPENDIX F - CONSENT TO PARTICIPATE IN RESEARCH

Computer Vision-Based Augmented Reality as a Tool for Illuminating Scientific Concepts in Educational Environments

Gabriel Resch, MI Candidate, gabby.resch@utoronto.ca

You are asked to participate in a research study conducted by Gabriel Resch, from the Faculty of Information at the University of Toronto, as part of research toward a Master of Information degree.

If you have any questions or concerns about the research, please feel free to contact Cara Kmpotich, Assistant Professor in the Faculty of Information, at [redacted] or cara.kmpotich@utoronto.ca

PURPOSE OF THE STUDY
The rationale for doing this study is to examine the viability of computer vision-based augmented reality as a tool for creating innovative pedagogy for tomorrow’s classrooms and science museums. It also seeks to gain an understanding of how research and development communities in educational software, museums, and augmented reality operate in parallel and communicate with each other.

PROCEDURES
If you volunteer to participate in this study, I would ask you to do the following things:
• Please respond, by email or phone, as to your availability for an in-person, over-the-phone, or web-chat interview. Interviews will take approximately 30 minutes and will be recorded.
• Please indicate how you would like to be contacted.

POTENTIAL RISKS AND DISCOMFORTS
There should be no potential risks or discomforts arising due to your participation in this study. You can respond at your own discretion.

POTENTIAL BENEFITS TO PARTICIPANTS AND SOCIETY
You have been chosen because of your experience and/or interest in one of the fields under study. Your involvement may contribute to the growth of knowledge in this field, the development of improved pedagogical tools, and may also provide valuable insight into potential techniques, ideas, or methods that can enhance your own work. Participants are encouraged to follow the research progress on the wiki: http://www.losingtime.ca/wiki/index.php/Main_Page

CONFIDENTIALITY
Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study. All participant identities will be anonymized, and all data will encrypted and stored on a secure database maintained by, and available only to, the researcher. All records will be retained securely for seven years.

PARTICIPATION AND WITHDRAWAL
Your participation in this study is at your own discretion. You may withdraw at any time without consequences of any kind. You may exercise the option of removing your data from the study. You may also refuse to answer any questions you don’t want to answer and still remain in the study. You will be required to notify the investigator by email or phone if you wish to withdraw. The investigator may withdraw you from this research if circumstances arise that warrant doing so.
RIGHTS OF RESEARCH PARTICIPANTS
You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. This study has been reviewed and received ethics clearance through the University of Toronto Social Sciences, Humanities and Education Research Ethics Board. If you have questions regarding your rights as a research participant, contact:

Office of Research Ethics
University of Toronto
McMurrich Building, 2nd floor
12 Queen’s Park Crescent West
Toronto, ON M5S 1S8
Telephone: (416) 946-3273
Fax: (416) 946-5763

SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I have read the information provided for the study “Computer Vision-Based Augmented Reality as a Tool for Illuminating Scientific Concepts in Educational Environments” as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____________________________________
Name of Participant (please print)

____________________________________
Signature of Participant  Date

SIGNATURE OF WITNESS

____________________________________
Name of Witness (please print)

____________________________________
Signature of Witness  Date