Discovering Familiar Places

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<td>As Published</td>
<td><a href="https://doi.org/10.1017/CBO9781139031127.025">https://doi.org/10.1017/CBO9781139031127.025</a></td>
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<tr>
<td>Publisher</td>
<td>Cambridge University Press</td>
</tr>
<tr>
<td>Version</td>
<td>Author’s final manuscript</td>
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<tr>
<td>Accessed</td>
<td>Thu Feb 07 22:38:02 EST 2019</td>
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<td>Citable Link</td>
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February 12, 2100: Walking down by the river’s shore it is hard to believe that as recently as a hundred years ago this bank of the river was dry land. Today all of this land is frequently under water as a result of increasingly wild weather events. Looking across the river you see the steady red light on the tower indicating that yet again, rain is in the forecast and people need to be ready to move to higher ground.

Traveling back a hundred years as a TimeLab researcher, you are surprised to learn that the risk of flooding was rather low in the past. Concerned for your family and friends, you think it would be great if the river didn’t have to rise – if this land could still be as dry as it was back then. Perhaps that is unrealistic and it is best to use this experience to prepare for still worse conditions in the future. But...perhaps it is possible that you can convince your ancestors to make a few small changes that will make your home in the year 2100 better....

The above scenario is part of the experience that players have during the Augmented Reality (AR) game, TimeLab 2100, developed at MIT as part of a series of research and development initiatives referred to as MITAR. The goal of MITAR is to provide experiences that merge the best of real and virtual in order to engage learners of all ages in games that are engaging, thought provoking, and fun.

MITAR has its origins in a series of Augmented Reality games developed at MIT and rooted in environmental science and public health. In games like Environmental Detectives (Squire and Klopfer 2007) and Mystery @ MIT (Klopfer 2008) players role-play as scientists, engineers and other members of the scientific enterprise as they try to solve local environmental problems through active research. This research consists of interviewing virtual experts and witnesses, reviewing primary documents and background research, and using virtual sampling equipment to obtain readings for possible contaminants in the air, water and soil. Since this game is Augmented Reality, it takes place in real space, such that if a player wants to interview the Mayor, they would need to stand outside town hall to obtain that interview on their mobile device. If the player wants to take a reading of the bacteria in the lake, they would need to walk down to the shore of that lake to use their virtual sampling equipment.

Players in these games need to integrate the virtual information they get on their mobile devices with their own observations in the real world. What is the slope of the terrain as it heads to the lake? How close is the nuclear reactor to the hot spot of contamination? Players role-play in different roles that typically characterize particular professions, such as an environmental scientist, a civil engineer, or a medical technician. The use of roles in these games promotes players individually making scientific connections, and also as team members collectively and collaboratively solving the problem at hand through data sharing, exchange of complementary information, and creative problem-solving.
While games like *Environmental Detectives* and *Mystery @ MIT* were designed to require players to observe, understand, interpret and integrate virtual and real experiences, it turned out that many players incorporated unintentional information from the real world. In taking action and making decisions, players would often cite the concerns of the real people they observed boating in the river, walking by the fictional “environmental disaster,” driving nearby, or simply known to have concerns in the community. In essence, they turned what was designed to be a “purely” scientific or engineering activity into one that incorporated both social and scientific concerns, which is a more complex, more realistic, and more engaging scenario.

The appropriation of additional real-world data into the games sparked the creation of new MITAR games that explicitly incorporated both social and scientific considerations. Augmented Reality in many ways (as detailed in the rest of this chapter) is an ideal medium for creating challenging and compelling experiences in which players must learn and understand socio-scientific issues, combining science, engineering, social science, and 21st century learning.

Later games have been designed explicitly to incorporate this balance of social and scientific – resulting in games that can be used for learning science, contextualizing research, and informing the public. In one of the more recent games, the aforementioned *TimeLab 2100*, players role-play as inhabitants of the early 22nd century in Cambridge, Massachusetts. Like previous MITAR games, the game is designed around a central theme that is real and relevant to players. Global climate change is out of control and players are given the opportunity to go back 100 years in time (roughly to our present day) to try and make changes that will ameliorate the situation. The catch is that the only thing the players can do is make small changes in the past in the form of getting items on the local ballot. Those items may either be measures to decrease global warming (e.g. provide incentives for improving home energy efficiency) or to decrease the inevitable impacts of global warming (e.g. raise roads out of a flood plain so that they will remain usable).

As the players are sent back in time to our present day they are split into teams that cover different territories. Players are also paired with each other, and each member of the pair is accompanied by a digital guide (Matt or Anne) who provides them with expertise in the scientific (Matt) or social-political (Anne) implications of the potential laws. In order to promote collaboration, players only receive half of the dialog between Matt and Anne (Figure 1) that they must then share with their partners. This collaborative mechanism enforces a simple jigsawing of information between the two players. Using the combined information players need to estimate the impact (high, medium, low) of a particular measure, as well as the likelihood (also high, medium or low) of that measure passing. Matt and Anne also offer their opinion on these factors.
Players in *TimeLab 2100* head out into their community to gather and weigh their options. A typical player experience starts out with everyone gathered in a classroom or meeting space. An incoming video transmission sets up the scenario.

**Hello and welcome to TimeLab, where our employees are never late. We’re thrilled that you could be here with us today.** As you know global warming has greatly changed the world as we know it. You are here to help us improve our world. **At the TimeLab we go back and make small changes in the past. For this mission a few carefully chosen laws will be placed on the ballot in Cambridge, Massachusetts way back in the 21st century.** We can’t force the voters to make good decisions. We’re not magic or anything like that. But we can hope that they make good decisions. If they do, TimeLab research has shown this can have a domino effect creating positive change around the world. As historical researchers you decide which laws will be placed on the ballot. **As you walk around here today consider two factors. 1) Which laws if they were passed would have the greatest benefit to society. 2) Which laws would be mostly likely to be passed in the first place. Then after you consider these two factors you will have a group discussion and make recommendations to us on which laws should be placed on the ballot. We’ll take care of it from there. That’s all. I’m going to send you off to meet some more of my colleagues from the TimeLab. Good luck. We’re all counting on you.**

Players then receive their roles, including whether they are to be guided by Matt or Anne, and which subsection of points they need to investigate. Matt and Anne are graduate students who understand the issues well, and can explain things clearly. Players are told that they have a fixed amount of time to gather the necessary information, after which they will come back inside and debate which three measures should be placed on the ballot. They then head outside together as a group where everyone sees the same small set of possible destinations on their screens, and their current real-world location marked with a constantly updating icon. After visiting the initial location with their partners, they are presented with some background information on the scenario, primarily what their guides will tell them. Matt and Anne describe a two factor rating.
scale for the possible measures they will encounter. One factor is the likelihood of the measure passing, and the other is the impact that the measure would have if it did pass. Each station that they visit will need to be rated on these factors based on the information that they receive.

After that initial point, each group is provided with six to eight additional destinations, each associated with a possible ballot measure. The points are clustered, but situated in places that make them contextually relevant. The player also may click on each of the points for a brief description of what they will be investigating at that point, allowing the players to plan convenient pathways, as well as pathways that explore a particular line of investigation.

For example, some players head to a Zipcar station where they learn about possibilities for expanding shared transportation options. When they arrive at the station, Matt and Anne describe possible models for car sharing that could be expanded, including possible legislation that would reserve parking spaces for shared vehicles. They describe the models in some detail along with how people might react to such plans and the impact that the plans would have on carbon emissions. After reviewing the information the players rate the likelihood of passing and the impact of the measure, during which Matt and Anne provide feedback. The feedback from Matt and Anne is filled with real research that is designed to help guide the players in understanding the issues around climate change. Understanding this information is the key to success in the game – getting the measures with the largest and most likely impact passed.

Continuing the line of reasoning around automotive transportation, the pair heads to another location, down by the river, where they learn that the road and sidewalk that they see are underwater in the future and need to consider what they could do to avoid losing that road. As the pair considers this measure, which assumes climate change is inevitable and must be prepared for, they note its contrast with the previous measure which tried to prevent climate change. The players discuss where they should place their emphasis – prevention or preparedness. Some of this conversation is generic, but much of it pertains to the particular circumstances in which they are situated. They consider whether the road that they are on could be relocated and what the impact might be on the local community. They talk about the local citizens and what they think would be possible to pass in this particular community.

After considering these measures and where they might rank them, players head off to explore a few more possible measures. In the end, they gather and consider six or seven different options relating to climate change, before heading back inside to debate. Each of the other groups has done similar investigations and brings that information to the table in the form of a 30 second pitch for their most important measures. The “augmentation” slips out of the way as players debate the science and policy surrounding the measures, recalling the information that they received from Matt and Anne, but also their own personal feelings and expertise.

After playing Timelab 2100 one student commented, “It really scares me to think that the place I call home might someday be underwater.” This shows that they connected the game world with their own community. TimeLab isn’t a game just about global climate change, it is a game about global climate change in their city – what it will do to their city and what they can do about it. Similarly another player said that they most enjoyed, “running around and seeing new things, the
way ordinary stuff was imagined as futuristic.” Feedback like this shows that players were able to connect the digitally represented future world with the real world of their own experience.

**AR and Science Education**

AR games in use today can be found most often in a variety of semi-structured learning environments, including after-school programs and at “informal” institutions like zoos and ecology centers. While these settings don’t carry the same testing and accountability requirements that schools typically do, there is still an overarching concern with what participants are learning. More generally, AR is being developed in a climate that is increasingly recognizing that *learning* is an ongoing continual process, with *schooling* or *education* representing only a small part of that endeavor (e.g. Collins and Halverson, 2009; National Research Council, 2009).

In their recently published *Learning Science in Informal Environments*, the National Research Council (2009) has offered a framework for what the NRC characterizes as “long,” “wide,” and “deep” learning in a range of situations and across the lifespan. While the report specifically focuses on science, it could just as easily be talking about learning in other academic fields with only modest adjustments. These strands are quite useful for understanding the value of AR games, both the ones we design (elaborated next) and for thinking through the potential power of putting design tools in the hands of youth (discussed later in this chapter).

**Strand 1: Sparking and Developing Interest and Excitement:** Our experience with using AR games with teachers and kids makes it clear that the game platform certainly sparks near universal interest and excitement. While some of this is no doubt attributable to something of a Hawthorne effect as the participants use unfamiliar tools (handheld computers with embedded GPS), we have seen even comparatively jaded adolescents become animated as they take on the personas embedded in game characters. Given the research base (e.g. Athman and Monroe 2004) on how learning correlates with strong interest, this enthusiasm can only help in promoting interest and excitement. In *TimeLab 2100* part of this interest and excitement comes from the theme of the game itself – climate change and the role of your own community. But part of it is somewhat more generic – understanding relevant scientific issues through a blend of the familiar and the unfamiliar.

**Strand 2: Understanding Scientific Knowledge:** Well-designed AR games can embed accurate and useful scientific information within the game scenario and clues. More importantly, the game scenario itself can model knowledge structures that are more helpful and appropriate. In *TimeLab 2100* players are challenged with understanding the scientific information that Matt and Anne provided for them to make decisions on the measures that will be put on the ballot. That understanding comes from reading the dialog with their partner, and evaluating the evidence that they are presented with for the later debate.

Another example of this strand can be seen in a recent ecology simulation one of the authors helped to develop. In this game 5th graders “interviewed” a variety of plants and animals found in the forest, with the challenge of settling an argument over who rules the forest. As the students proceeded through the game, they repeatedly encountered the interdependencies that members of
an ecosystem must live with. While the kids already “knew” interdependence as an abstract concept, playing the game modeled how these connections work in a real ecosystem, much more than did their textbook food web diagrams. The students were also able to draw on what they knew of Missouri bottomland forests to fill in their mental images of who eats what, leading to a richer overall learning experience.

**Strand 3: Engaging in Scientific Explanation and Argument:** AR games offer opportunities to engage players in scientific explanation and argument, both in the design of the game and in moving toward a resolution of the challenge embedded in the game. As players encounter non-player characters, these NPC’s can be used to model effective scientific thinking (or perhaps even model ineffective thinking with the ensuing lack of success). This might involve the NPC showing how to think about data, what to observe, and how to draw conclusions based on evidence. In turn, a well-structured AR game will require that the “live” players collaborate in developing a proposed solution to whatever the problem situation is for the game. As they do this, they will be engaging in scientific explanation and argument as they debate the relevance of various field observations and data points players have accumulated over the course of the game.

The culmination of *TimeLab 2100* is explicitly designed to encourage debate and argument around the elements that will be placed on the ballot. Players need to individually prepare their arguments for the debate, backing up their opinions with the evidence that they have gathered in the game (as well as legitimate outside evidence). As in real science, there isn’t necessarily a single answer, so the players must evaluate and weigh the evidence that they have.

**Strand 4: Understanding the Scientific Enterprise:** In conjunction with the previous strand promoting scientific explanation and argument, game players come to understand the larger scientific enterprise as it is modeled for them by the non-player characters and in the tasks the players undertake. For example, in the previously mentioned *Environmental Detectives*, players come to understand how environmental scientists monitor creek health through analysis of biotic and abiotic water quality data and field observations. But they also understand that equally important in such an investigation are background research in the library and laboratory, as well as conversations with other experts and witnesses. Later games such as *Mystery @ MIT* integrate role-play – scientists, engineers, reporters, analysts, doctors, and technicians. They get the experience of walking a mile in each of those professions’ shoes, while also figuring out how they all work together as part of a larger investigation. Given persistent misconceptions among students as to who a scientist is or what one “looks like” (e.g. Chambers, 2006), a well-crafted game environment will engage players in seeing and doing “real” science.

**Strand 5: Engaging in the Scientific Process – Using the Tools and Language of Science:** Continuing in this vein, players in a well-crafted AR game use simulated and/or real data collection tools as they pursue investigations. Since many of these tools are too expensive, sophisticated or dangerous for use by younger students, virtual tools help players see the horizons of science they can aspire toward. Likewise the non-player characters model the language of science as they use key terms like hypothesis, experiment, data, and conclusion, each in a meaningful way that helps move the game along. In turn, players (by themselves and with the guidance of teachers or group leaders) practice the use of this language as they interpret what they observe, discuss alternative strategies, and propose solutions to the underlying challenge of the game.
For example, in *Mystery @ MIT* players need to draw various AR samples from the air, water and soil. Rather than having perfect information about the extent of contamination, they are limited in their tests by their resources, and thus need to figure out where and when they should be sampling. When they receive samples back they need to be able to interpret them, not only understanding their units, but they need to understand variability (in both what they are testing and how they are testing) as well as what is “normal” for those samples.

**Strand 6: Identifying with the Scientific Enterprise:** Given the importance of students’ building scientific interest and literacy, it is essential that steps be taken to build a greater affiliation with the scientific enterprise. While only a portion of today’s students will actually go on to be scientists, all of us need to vote on emerging issues that affect climate change, medical research, and other domains. Whether it is used professionally or not, disengaging with a scientific worldview is in some ways tantamount to disenfranchising one’s self. A more pressing consideration for younger people is the necessity of not limiting potential career options. Given the extent to which certain classes like Algebra I serve as “gate keepers” (U.S. Department of Education, 2008), youth need to be encouraged to keep their options open in their course selections. “Moving up” in levels of science and mathematics classes becomes difficult both in high school and college once a track has been settled into. Motivating an interest in STEM-related fields through engaging learning environments such as an AR game is an essential component of building and maintaining identification with science as a possible career choice.

AR games such as *TimeLab 2100* make this connection through the use of real world issues of concern, presented in an understandable and often humorous way. The guides Matt and Anne provide a sense of humanity in the context of the scientific investigation. They, like the other NPCs in *Environmental Detectives* and *Mystery @ MIT*, represent the diversity of science and engineering fields (including the intersection with social science) as well as scientists. The AR delivery, whether it is through text, images, or video shot onsite, makes the scientists and engineers relevant and accessible.

**Augmented reality and place-based education**

Augmented Reality (AR) games or simulations offer a number of potential educational benefits, but the overarching and comparatively distinct affordances derive from the capacity Augmented Reality has to overlay the virtual on the real. Doing this, AR games promote and extend an educational approach commonly known as place-based education. In a place-based approach, a student’s own community serves as the setting and the motivation for wanting to learn more (Sobel 2004). That is to say, students are more likely to care about the investigation if it’s in a space that matters to them. Water quality in the creek my dog drinks out of is more important to me than an abstraction like water quality in the Gulf of Mexico’s “dead zone.” This isn’t to say that all learning should only be local; however, it is true that if a project affects people or places close to me, I’m more likely to care. Research data drawn from a national collaborative of place-based projects (PEEC, 2010) documents enhanced teacher motivation as well as improved student learning, stewardship interests, and community involvement. As they become part of the subsoil of school culture, place-based projects have been shown to transform school culture and to foster lasting connections between schools and their community.
From a gaming perspective, the primary benefit of embedding the project in the player’s own community is seen in the fact that the player with local knowledge has intimate personal experience with the space, which allows a much greater degree of context and nuance to be brought to bear on the problem or investigation at hand. At the very least this improves the authenticity of the experience, as even the most richly developed virtual world is still at its core a model, lacking in those details. If you’ve ever taken a guided tour of an unfamiliar city, you’ve experienced how a locally informed guide can fill in the spaces between highlights, bringing your attention to the fascinating details that would otherwise be overlooked. As you gain experience from repeated visits to that new city and become more of a “local,” you too will build a network of meaningful observations and associations. Not all of these can be fully articulated, but to paraphrase Michael Polanyi (1974) we all have spaces where we “know” more than we can tell about. Our tacit knowledge of familiar places is unquestionably an aid to understanding.

The risk here, of course, is that things that are too familiar might be overlooked, so it is incumbent upon the AR game designer to leverage this local knowledge effectively. Attention must be drawn to key features, in a sense “activating” them in the player’s mind. What does that drainpipe carry? Where does it come from? Once activated, that pipe can serve as a talisman pointing implicitly to a range of understandings about community geography and local environmental issues. In the case of the drainpipe, knowing that there is a golf course and a mulch pile upstream may help a player solve an environmental mystery. A good AR game can, in the words of anthropologist Clifford Geertz’s classic aphorism, “make the familiar strange,” enhancing appreciation and intrigue, while at the same time drawing on things we have known all along. For those who prefer a more poetic ring, T.S. Eliot (1968) offered these words of advice that can be valuable for an AR game designer:

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We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.
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Brought forward to the cognitive level, this web of personal experience in the space allows facts, observations, and prior experiences to be used in solving the underlying puzzle or mystery, filling in the gaps around the information provided by the game.

More generally, players who are actually positioned in a real-world space have to “read” a much more complex landscape to determine what is relevant or not. This filtering of the relevant from the non-relevant helps develop players’ cognitive sophistication as they learn to discriminate what is a useful clue. Does it bear on the issue at hand? How can I use this to solve the mystery? When the AR game encourages or requires collaboration among players (for example, by embedding multiple roles into the game), this benefit of drawing on knowledge of the community has the potential to increase understanding considerably, since each participant brings their own local experience to the pooled effort. As the colloquialism says, all of us know more than any one of us. The “mental game space” increases with more players, as does the opportunity for productive communication, collaboration, and cooperation.

A traditional video game (whether it is software, web-based, or a hybrid) will provide requisite clues and perhaps some red herrings, but it won’t be able to activate a player’s web of tacit and
explicit local knowledge, since it is ultimately an abstracted representation. While virtual environments are certainly becoming much richer and more realistic, there is still an air of artificiality and ultimately, of simplification. Observing what is real brings layers of authenticity that can support players’ broader learning. A rock could be represented as a set of pixels on a screen, but a real rock that has bulk, size, texture, and a broader palette of colors provides a multi-sensory experience. Even the most complex of virtual game spaces is limited to what the designer chose to place in the game, inevitably constraining choices to a set of pre-arranged options. These can be diverse and just as challenging, but they will inevitably be limited to a finite number.

Of course, this constrained palette can be beneficial in a game environment, particularly with younger or less experienced players. At some point, too much choice can be paralyzing as minor variations serve to confuse more than they help (Schwartz 2005). These are ultimately choices for the game designer; our point here is simply that there are certain benefits to be derived from experiencing the real world, both for the game play and for broader educational development. All too often, young people have limited contact with nature (Louv 2005); AR gaming is a means to get kids outdoors to expand their range of experience.

**AR and community stewardship**

In addition to the technological innovation described later in this chapter, a major strand of our work with AR games seeks to leverage gaming to promote community stewardship, as this is the logical outgrowth of a place-based learning experience. If I care about a place and come to know it, I’ll want to make a difference. Our two major collaborations – Local Investigations of Natural Science (LIONS) and Community Science Investigators (CSI) – are each funded by the National Science Foundation to investigate the educational benefits of technologically rich out of school time (OST) learning environments.¹ Both projects run after-school and summer programs for upper elementary and middle school students, led by classroom teachers hired by the project for the extra duty. Students use augmented reality as one component of a larger effort to link games, computer mapping tools (GIS and GPS), and stewardship projects. So, for example, students might play a game that introduces them to water quality issues in the local stream, map out pollution sources, and engage in a stream bank stabilization project to mitigate the pollution they found. Closing the loop, students might create an original AR game to engage others with local aquatic ecology.

In each project we are testing the premise that the AR game serves as a catalyst to enhance interest and to build understanding of key conceptual elements of the general topic being investigated. So, for example, imagine Eric – a 6th grader in suburban St. Louis participating in a LIONS project – playing an AR game built around a pretty typical environmental mystery: What is causing pollution to appear in the stream? The key difference provided by the AR environment is the awareness it builds in him of the potential sources of pollution in his neighborhood, including a dog park that he didn’t pay any attention to previously. As he noted, “I probably never noticed it before” (Crawford 2008). A well-designed game has this potential to bring

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¹ Local Investigations of Natural Science is funded under NSF grant #0639638; Community Science Investigators is funded under NSF grant # 0833663. Opinions expressed here are those of the authors and may not be those of the National Science Foundation.
forward aspects of the community that are often overlooked...an educational version of “making
the familiar strange” and noticing what is all too often taken for granted. By the end of the game
Eric and his partner were drawing plausible conclusions about what might be causing the
pollution in his local park, considering their own observations, the data provided in the game, the
spatial locations of the sites, and the time sequence of events (such as a rain storm and an
imaginary dog show that potentially would increase the fecal coliform load in the creek) relative
to when the pollution was documented. This orientation provided by the AR game provided
useful context for subsequent water testing in the park done by the LIONS group, and it
motivated them to participate in stewardship projects to improve the park.

Combining AR with stewardship projects has the potential to create fusion between two major
youth motivators. As readers of this volume are well aware, substantial numbers of young people
find game play enticing. Add to this the motivation many young people feel to be involved in the
community (Hart, 1997) and there is a potentially powerful combination drawing on different
interests. The game environment that may be appealing to a more technologically-oriented youth
can lead her to increased interest in community involvement, while a civic-minded youth that
may not see himself as much of a game player can expand his technological horizons as he
engages in AR play through the larger project. Motivation through community engagement in
turn links back to academic achievement, as documented in a recent EPA study (Duffin, Murphy,
and Johnson, 2008) comparing learning outcomes in projects that have an action component with
ones that have only an academic base.

Students as AR Game Designers

It should be clear at this point that playing an AR game offers considerable potential for
engaging students in learning about their community and then using what they know to make a
difference through stewardship projects. In our experience, students can go even further when
they become game designers. Using a continuum from playing to modifying and then designing
original games, we have scaffolded students as young as 4th grade in the creation of original AR
games. This work promotes development in a number of academic areas, including spatial
thinking (as they work with aerial photos representing the game site) and language development
(as characters are created and background information is drafted). Logical thinking is also
promoted as the young game designers plot out the sequential flow of the game.

Beyond these general academic growth opportunities, game design supports growth in
computational thinking – an increasingly important skill in a technological world. Computational
thinking (CT) describes an approach to framing problems or issues that relies on two main
pillars: abstraction and automation (Wing, 2008). Or, as Dave Moursund (2009) describes it, “the
underlying idea in computational thinking is developing models and simulations of problems that
one is trying to study and solve.” In an AR context this plays out as designers create a series of
abstract iconic representations of non-player characters and objects, and then develop
hierarchical branching “rules” for how they interact (e.g. which follows which sequentially, and
planning out when individual items appear on the screen). The software automates these
intentions, leading to a finished game in relatively short order.

An additional benefit of students serving as game designers is seen in the ways that game design
enhances students’ awareness of their neighborhood. In terms of developing a sense of place, AR
designers need to be intimately aware of the game space. Simply dropping points down on an aerial photo won’t suffice. Instead, a detailed study of the game site is critical. Where can players observe key sites that might be affecting water quality? In which order should they be explored? Or, for an historical mystery: What clues in the community “speak” to the past? Is there an old building foundation nearby? What used to be there? Who used to live here? All of these make the local community real and relevant to the game designers (and in turn the players). Effective designers need to get out of Mom’s mini-van and start walking around, since the best AR games make creative use of the neighborhood. Their mentors can support this process through guided exploration, looking for potential sites. Many of these sites will be left on the cutting room floor, so to speak, but the process of seeing the neighborhood as a game space provides students with a new lens on where they live. The familiar becomes strange as a sequence of possible sites and artifacts are considered for possible inclusion in the emerging game.

Over the last five years, we have observed hundreds of children engage with the various versions of our design tools to develop AR games. While we still have much to learn in terms of how to empower novices to use these tools effectively, here we provide an aspirational vision to further illuminate the power of positioning youth to design with these tools. We have examples of designs that are both less and more productive than the synthesized account we present here. The following scenario, synthesized from a number of experiences in summer and after-school programs, illustrates the ways in which AR authoring contributes to science learning:

Small groups of two or three students each dot the park near a middle school just outside of Milwaukee. Michaela and Jenny pore over a paper printout of a map they have from their earlier work in the computer lab, and compare it to the smaller view of the area provided by the handheld computer Jenny is carrying. As they move through the park, they become more and more engrossed in conversation about features of the landscape they plan to use in the MITAR game they are building. Soon they approach a water fountain next to the fenced-in dog run at the far corner of the park. Observing more closely, the girls notice that there are insect larvae growing in the water sitting in a dog bowl near the fountain.

After a quick round of “Ewwww’s”, they latch on to an idea for their game. “I bet those are mosquitoes,” Michaela comments. “I know!” Jenny exclaims, “Our game can be about mosquitoes bothering people and dogs when they come here for walks!”

Michaela picks up on this thread, adding, ”Yeah, all of them are out more in the mornings and evenings. We can even pretend that some players get diseases from the mosquito bites.”

With that, they snap a few photos of the larvae, of themselves in front of the dog park sign, and of the school in the distance. Then they head back inside to catch their rides home.

The next week, Jenny and Michaela are even more excited about their game. They’ve been talking about it with each other and a few adults, but they’ve been careful not to give anything away to their club-mates, who will be the first audience for the game they’re creating.

The pair has a very full hour-and-a-half work session this week. They start by downloading the photos they took the week before onto the computer. After seeing the photo of the larvae and
another chorus of “Ewwww, that’s so cool.” they search the web for a good photograph of a full-grown mosquito. Having found one, they settle in to write the dialog for one of their main characters, Marvin the Mosquito. At the same time they realize it would be fun to write some of their classmates into the story to make it fun and meaningful to their peers.

Part way through writing the dialog, though, they realize they don’t know what diseases mosquitoes in Wisconsin carry. “Ms. Weisman”, they shout together, “we have a question!” After a whispered conversation with Ms. Weisman, a teacher from their school running the after-school program, they look for information about some of the nastier diseases that affect dogs or humans and are carried by mosquitoes in the Midwest. As they do this they are filtering their results mentally, looking for how what they are learning is relevant to their game. This research generates a lot of discussion between the two girls – What density of larvae in the water dish allows the mosquito population to grow? and How long does water need to stand before it becomes a risk for breeding larvae? And most contentiously, “Should the park continue to leave dishes out for thirsty dogs (and mosquitoes)?”

Another couple of busy afternoons later, Michaela and Jenny are back out in the park. They walk carefully through the game they’ve made and take notes about the relative positioning of game “hotspots” – the water bowl that they had noticed on their first trip out (which now can be virtually “sampled” for larvae), the nearby pond, and the preschool playground on the far side of the park. They also note small spelling errors this time through, and one major “oops” – an important character that doesn’t show up when she should.

Finally, after a few tweaks to the game later that afternoon, they’re ready to show it off to their fellow club members the following week. All week, they wish for good weather, and to their delight, it’s all systems go when Wednesday rolls around. The handhelds all have their game loaded and ready to play, they haven’t given away the ending (they hope), and like proud directors, they nervously watch as the first audience starts to play the game they’ve built. If all goes well, their peers will not only have a fun time playing their game, but will learn something about potential dangers of mosquito-borne illnesses and what they as a community can do about it.

This experience demonstrates some of the many ways that authoring of AR games engages students in science knowledge and practice. Thinking back to the six strands from the National Research Council’s Learning Science in Informal Environments report, we see how those play out for Jenny and Michaela:

Strand 1: Sparking and Developing Interest and Excitement: This is perhaps one of the greatest strengths of AR authoring, combining real world kid-friendly issues, game play, and immense levels of personalization and customization. As the girls illustrate, there are many points of engagement in this experience. Finding the “smoking gun” of the dog water bowl, writing dialog for their friends, taking on an issue that they have identified as relevant, and creating work for their peers all combine to create an experience that captured their attention and interest in different ways. This illustrates the potentially broad applicability of game design as an educational hook, as it captures the interest of people who like to wander around in the park, do research, write fiction and/or non-fiction, work with digital media, and a range of other tasks.
All of these are relevant to this experience. Collectively, this range of hooks helps to bring people in, and over time develop real interest and excitement about science.

**Strand 2: Understanding Scientific Knowledge:** The scientific knowledge in this case includes field investigations of potential breeding grounds for mosquitoes, background research on mosquito-borne diseases, construction of plausible data on mosquito larvae densities, and studies of the impacts of different interventions. While these investigations could be as simple as a quick Internet search, creating a scenario that is satisfying to the authors and compelling for their peers will involve much more than that. Just as a movie audience is unsatisfied with an implausible ending to a mystery (*how were we supposed to know that?*), so too a game’s audience will be unsatisfied with disconnected clues and consequences not related to choices they have made within the game space (Barab, Gresalfi, and Arici 2009). AR authors quickly learn this and construct their game so that it contains the information, challenges, and sequences needed to make the game a better experience for the players.

**Strand 3: Engaging in Scientific Explanation and Argument:** The girls had many issues to debate, including the evidence that they were embedding in their game and the merit of different actions that could be taken. In the end, the best game experience for players is the one in which they are required to weigh evidence and make the meaningful decisions. That means the authors need to thoroughly consider the nature and amount of evidence that they supply in the game for the players. Creating the basis for players to have thoughtful deliberation around the issues requires authors to have an even deeper understanding of the issues and how they relate to each other.

**Strand 4: Understanding the Scientific Enterprise:** For many students, the scientific enterprise is “bench science,” something that individuals in white coats and goggles do in the laboratory. Students who use a multitude of sources while creating AR games begin to realize that the scientific enterprise is much larger than just bench science. They collect field data through observation and analysis. They do background research on issues at hand using digests and primary research. They see that science is integrated – chemistry, biology, and earth science are all parts of one whole. And they also see that science can be concrete, as they use basic science to improve the lives of others in their community.

**Strand 5: Engaging in the Scientific Process – Using the Tools and Language of Science:** AR games put unlimited tools at the disposal of authors. One can create virtual versions of any kind of scientific sampling or analysis device imaginable. But doing so in a reasonably realistic way involves considerable understanding of that data and the tools used to measure it. In this case, the authors wanted to allow players to “sample” larvae from different water sources that they encounter in the game. They needed to think about what devices they would virtually provide to the players and how those devices would collect and analyze the data. To provide players with a greater understanding, they even wanted to put in scans of microscope slides showing larvae. In terms of the language of science, note that the authors need to write about all of this using accurate dialog involving characters of many kinds: medical personnel, community members, and even mosquitoes. In each of these dialogs they need to consider both what the character’s message is and how that message is conveyed.
Strand 6: Identifying with the Scientific Enterprise: The reason why the girls chose to develop this game is because they made a meaningful discovery on their own. While it may seem mundane to us – a standing source of water in the park – it provided meaning and purpose to their game. While the story in the game may be fictional, the experience for them is quite real. Building on that initial spark, they conducted research on a variety of scientific issues and procedures, resulting in a greater understanding of how and why the scientific enterprise is relevant to their lives. And by embedding the work within familiar life spaces, the work itself is more likely to “rub” up against and become part of their personal lifeworlds (Barab & Roth, 2007).

Student-Friendly Tools for AR Game Building

The earliest Augmented Reality games built in MIT’s Scheller Teacher Education Program lab embedded game objects in an XML file. Readable by only a small number of people, this format required arcane knowledge of the file format to implement a game. To allow broader use of this game format, the need for a game editor usable by a technically savvy non-programmer became apparent. And so came the MITAR Editor, a drag-and-drop graphical user interface (GUI) for editing Augmented Reality game files. The MITAR Editor, currently at version 6.0, enables a game designer to implement all the possible features of MITAR games, including:

- items and non-player characters (NPC’s) – icons on a game map with which players can interact when they are physically within range of that map location;
- triggering and anti-triggering of game objects – allowing the game designer to set game objects to appear or disappear after other game objects are visited;
- roles and chapters – segmentations of the game by time and by fictional player roles;
- spills – virtual gradients of a substance from some epicenter that players of the game can take samples of;
- portals – game objects that allow players to move from one game map to another;
- and numerous other features.

The MITAR editor’s flexibility and rich set of features allow game designers free rein to build complex games. In reality, however, most games built do not take advantage of all of, or even most of, the features available. Furthermore, seemingly simple game building tasks require the builder to delve several layers deep into the interface. For example, to add text for an NPC requires the builder to double-click on the icon for that NPC to open the Properties dialog box, select the “Info” tab, select whether to specify settings based on role and chapter or not, and then click the “Add” button to add a new page for the NPC which opens another dialog box within which the builder can type the text for the character, unless, of course, the builder wants formatting for the text, in which case they should choose the “File” option. This level of complexity makes a novice designer put too much focus on the software and not enough on the game design.
As plans unfolded to have middle school aged children build their own games, the desire for a simplified game building tool grew. And so, the MITAR GameBuilder was created. This tool, also a GUI-based tool, edits the same game files as the MITAR Editor, but has a much cleaner, simpler, and more intuitive interface. GameBuilder does not allow the designer to use all the features of the MITAR Editor. Instead, it presents the tools to do the most common tasks easily and quickly. For example, to add a character with dialog to the map, the designer simply clicks the “Add Person” button, which leads to a three-step wizard that allows the user to specify the name of the character, a picture to use for the character, what the character says, and then place the character on the map.
Early formative assessment of a version of GameBuilder that did not allow users to trigger or anti-trigger (turn on and off) items and characters showed that students easily used the tool to build linear narratives, in which players moved from one point to another through the game. In order to promote more complex game play, the current iteration of GameBuilder allows these triggers and anti-triggers, which enables students to build games in which their players have to make choices as they move through the game. Work continues as GameBuilder evolves to enable students to design complex games in a supportive software environment.

Looking more broadly: Using AR gaming to build students’ creative agency

In addition to the academic and community benefits described so far, AR gaming offers a heightened capacity to develop students’ agency as they play and then create sophisticated products valued by their peers. Typical western school models devalue student ownership of their learning and their ability to make a difference with what they know. Instead, most schools are formed around a banking model (Friere 1993) where students are expected to make deposits for future benefits. Learn everything, just in case you need it some day.

AR game design projects turn this worldview upside down. Playing a well-crafted game that involves consequential choices creates a space for autonomous mastery. Typical school assignments are highly prescriptive in their scope and deliverables. A game with multiple
branching options puts more of a burden on the player to make wise choices and to experience success or failure based on the soundness of those decisions. With experience, the player’s success rate improves.

As players become designers, the possibilities of student ownership of their learning increase considerably. Designing original games allows an iterative cycle of creation to be followed, as designers imagine, create, and play games as a shared experience that is followed up by reflection (Resnick 2007):

When you contrast this producer / consumer (or “pro-sume”) model with the more typical “learn this because you will need it when you get a job” message that school provides, it’s not surprising that many find their out-of-school lives more enriching than school. In terms of autonomous control, self-direction, and sense of efficacy, out-of-school-time (OST) learning is often both more rewarding and more cognitively complex. In light of this gap in approaches to learning, we have found the greatest success in using AR in after-school and summer learning environments, as well as in partnership with informal science institutions. We do, however, have some formative experiences using AR in regular school classrooms and hope to expand that dimension of our work in the near future.

We noted earlier that a great deal of creative effort is expended in the creation of the games, but there is the potential for as much or more growth in the sharing and reflecting phases of the project. Abstractions are called into question as designers work together to consider the objects and non-player characters: Are they well created? Do they share just enough to create an interesting game scenario? Rule making as a form of automation is also critical to the success of the game: Is the sequencing right? Are there enough plausible alternatives to make the game challenging? Ideally this happens in a mutually reinforcing studio environment where students can become critical connoisseurs of good design (Hetland et al, 2007) and learn from more experienced peers (Smith, 1987).

At the risk of over-simplifying the distinction, traditional schooling is founded on a stimulus-response mindset, where students are expected to respond in predictable (and approved) ways to
the stimulus provided in the form of lessons, tests, and grade. Contrasted with this stimulus-response approach, AR gaming embraces a sociocultural view where the student becomes a competent social actor exerting agency (Emirbayer and Mische, 1998), or the ability to influence the world around them. As Resnick’s iterative cycle moves forward, students build an experiential base that informs successive designs. This base likely includes a combination of competencies developed through previous experiences, including:

- Technical skills with computers
- Competence with the AR game design software
- Knowledge of the local community where the game will be played
- Understanding of content relevant to the game, and
- General knowledge of what makes a good game.

Phrased most broadly, each of these elements can be thought of as strands where continuous improvement is both possible and required for any significant growth as a player or designer. Through incremental learning, competence grows. As Dweck (2000) describes it, this “incremental” frame for learning provides a more solid foundation for future learning than the “entity” frame that treats competence as something you either have or don’t have.

Returning to the consideration of agency, an AR player or designer draws on an experiential base developed over time to envision future alternatives and make rational decisions about the potential success of each. As he or she gains experience, these projections are increasingly well-founded (again, drawing on what has been learned in previous iterations), drawing on visions of what is possible given what she knows of the different strands identified above. Comparative depth or lack thereof in any of those will inform or constrain the quality of the projections.

Living in this dynamic tension between past iterations and future projections, the player / designer is cast as an active decision maker rather than as a passive reactor. As Emirbayer and Mische (1998) frame it, the student is involved in a process of “practical-evaluative” decision-making that draws on previous iterations and is guided by the projections. As a creative agent in the process, choices the student makes have an impact on how well he or she succeeds in a task meaningful to the student. In Barab et al’s (2009) terms, the game play is “consequential” in that the choices made have an impact on the player. Good game play builds the player’s capacity, which influences future design skills and opportunities to engage in stewardship projects informed by what was learned in the game space.

**Augmenting the Already Strange: AR in Informal Learning Settings**

While schools and their neighboring communities offer many possibilities for digital augmentation to “make the familiar strange,” other locations, by their very nature, are already decidedly “strange.” That is to say, they are unusual in that they are places of interest. These places, including museums, zoos, nature centers, botanical gardens and historic locations, offer special, often unique opportunities to engage visitors with an intrinsically rich physical setting including unusual objects, animals, natural phenomena or other striking features.

Such locations already offer visitors interesting experiences, and often use docents or signage to suggest frames through which to understand the exhibits. Still, these locations can benefit from utilizing AR to suggest additional frames through which visitors can see the exhibits. In an AR
A game developed for Boston’s Museum of Science, visitors (many of which were museum members and therefore self-identified as very familiar with the permanent exhibits) were embedded in a mystery game. To succeed at the game, players needed to view the exhibits through the lens of “codes”, prompting players to consider the exhibits in ways they had not previously done. Players were surprised, for example, to find particular exhibits they had never seen before, and to see exhibits they “knew” in a different light. In this way, the museum was able to create new experiences by providing a digital lens for visitors, all without significant changes to the artifacts themselves.

In the Museum of Science example, cracking various “codes” became a compelling vehicle to engage visitors with a variety of exhibits. However, AR games can prompt more thoughtful consideration of weighty issues. In our work with the Columbus Zoo and Aquarium in Dublin, Ohio, we have sought to make AR games which do this, in both an engaging and enjoyable way. In our first zoo game, Zoo Scene Investigators or “ZSI”, we targeted 4-8th graders layering content about the illegal wildlife trade within a mystery set in the Zoo’s Asia Quest exhibit area. Imagine the following scenario, drawn from real observations of students playing “ZSI.”

Shayla and Tasha are 6th graders from Columbus, Ohio spending the day with their class on a middle school field trip to the Columbus Zoo and Aquarium. As part of their trip, they are playing an Augmented Reality game called Zoo Scene Investigators (aka “Z.S.I.” spoofing the popular television series). The pair is seated with four classmates and a chaperone around a round table in the Pavilion building. Shayla and Tasha fasten the badges to their jackets which identify them as the “detective” role to their teammates. They also pick up their handheld computer, which Shayla starts to play around with as Tasha watches closely.

The lights dim, and an introductory video begins...

Last night, something strange happened at the Zoo. A strange man was caught trespassing on the grounds after the zoo had closed to visitors. Before the security guard was able to tackle him, he ran all over the Asia Quest area of the zoo, tossing items he had been carrying. When he was eventually tackled, he had nothing but the clothes on his back. He has no ID and so far, has revealed nothing about himself or his motives during questioning. You – the famous Zoo Scene Investigators – have been brought in to gather evidence at zoo, try to figure out what he was up to.

The video ends and Shayla and Tasha wonder how they’re going to solve the mystery. What was that guy up to last night? As Zoo staff give some additional instructions about how to play today’s game, Shayla and Tasha walk outside, along with their chaperone and teammates, and watch excitedly as their handheld’s GPS indicator turns on, showing their current location on an aerial map of the zoo. They then do a brief “walking tutorial” during which they discover various virtual objects and even a talking goose along their path, including a mysterious empty box with a note suggesting that the box used to contain items confiscated because they were part of the illegal wildlife trade. After the tutorial, the zoo staffer sends them off with their teams to investigate.

None of Shayla’s team has been to the zoo before, but Jasmine immediately takes on the impromptu role of navigator. Looking down at the map on her handheld's screen, she watches the orange dot which shows her present location move around as the walks down the path,
turning the handheld device until she sees herself moving in the same direction that she's walking. “C’mon – it’s this way” she yells back over her shoulder as she waves to her teammates.

The students pause when they see a food vendor, but Kenneth quickly corrals his team to stay focused. Kenneth asks his teammates what they’ve discovered and shares what he knows with them. He tries to keep everyone moving and paying attention to the details.

The students arrive at their first game icon, a sun bear that tells students about suspicious behavior he saw last night. The Detective teammates paraphrase what they learned from the sun bear. Their team chaperone Mary, a class parent, asks Tasha to repeat what she said, so she can take notes in her printed Chaperone Guide (which includes sequential prompts/questions to help the chaperone, who does not use a handheld, keep up with the complex multifaceted activity).

The bear mentions that the man dropped something shiny. One pair of students is now looking for a real shiny object in the bear enclosure. “No, I think we’re supposed to look for a clue code...” Shayla looks up and sees a clue code posted on the upper beams of the enclosure where they’re standing. She points out the special printed card displaying a four digit “clue code” to her teammates. The students enter the code in their handhelds and another role learns that the shiny object was in fact a tranquilizer gun. The gun suggests that he was going to sedate but not kill the sun bears. The students learn that baby sun bears are captured and sold illegally as exotic pets, but that they do not in fact make very good pets. People sell bears and other wild animals as pets? Really? That’s wrong.

This evidence helps their case against John Doe and they continue to other locations around Asia Quest, gathering evidence from an elephant, whose evidence suggests that the intruder may have been trading in ivory, illegally poached from elephants and may have been after the tusks. They also speak with a tiger, who thinks the intruder might have been after his pelt, and the markhor, whose antlers are prized as trophies and are ground up for use in some cultures traditional medicines.

After gathering all the evidence available in the Zoo, the team heads back to the Pavilion. As the students file into the building, the group's chaperone nudges their classroom teacher. She mentions how engaged the group was, and her surprise that Kenneth was especially engaged. The teacher concurs, mentioning how Kenneth is typically distracted by his friends and often disinterested in his academics. His leadership role this morning was an unexpected surprise.

The activity wraps up with discussion of the evidence the teams found throughout the zoo. The facilitator deems the evidence sufficient, and John Doe provides a confession in the form of a video in which John Doe confesses to his various dealings with the illegal wildlife trade.

**Concluding Remarks**

The potential gains of using location-based gaming in formal education are substantial. AR games can connect formal concepts to concrete realities and motivate student learning through connection to their community. With these connections, this technology naturally also creates
service learning opportunities. But as we have discussed, the limits of the current approaches to schooling frequently inhibit this implementation in schools, while still permitting AR to be a fun and useful technology in after school and informal environments.

If models of schooling evolve toward greater emphasis on sustained inquiry and student-driven investigations, we can envision a bright future for AR in the regular classroom. From a technological point of view, mobile technology (and access to that technology) is changing rapidly. A few years ago it might have been considered absurd to think that everyone would have access to the Internet wherever and whenever they chose via pocket-sized devices. Today that ubiquity is nearly a reality. Similarly, web-based tools are dramatically simplifying the way that people access applications and their associated data. This increase in ubiquity and broad accessibility of devices, combined with ease of implementation brings with it an opportunity for innovation in the classroom and beyond.

AR games could then become “just” another form of user generated content – created by the masses, shared to like-minded peers, and mashed-up by many. This removes the technical challenges to implementation in schools, enables students to be able to play games as a part of their daily lives, and puts game creation on par with a host of other Web 2.0 tools that students readily master without extensive instruction. At this point the teacher could focus on learning and experiential objectives instead of being burdened with device management and technology overload. Students gain because AR games aren’t a closed experience done in a few hours or a few days, but rather something that becomes a part of their lives – something that they can use to share their own ideas, develop new understanding and learn from others.
References


