Digital games for analogical thinking and conceptual science learning in the middle grades

An update on the work of Possible Worlds, a National Research and Development Center on Instructional Technology

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For more information,
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I want to start by acknowledging that this work reflects the ideas and talents of many people. My colleague Shelley Pasnik is the director of the Center for Children and Technology and has been a great leader for this work. Cornelia Brunner, is really the driving force behind many of the ideas that really anchor the design f these games, and much of what I'm saying today is based in her thinking, so I hope that I'll represent her ideas well. Tobi Saulnier and her whole team at 1st Playable have been amazing partners throughout this project. And I want to thank Ed Metz, for being incredibly supportive and generally a dream program officer.

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There are three driving questions behind our project, and I expect they look familiar to many of you, though they reflect our particular approach in some ways. These are the three issues I'll be trying to address throughout this presentation. Can we make digital games that will:

1. Enhance existing instructional environments?
2. Play meaningful, specific roles in an iterative, multimodal teaching and learning process?
3. Make possible improved outcomes on hard-to-teach, hard-to-learn concepts?

Across each of these questions, you'll notice that we have largely left two important projects to others. First, there are many projects that are investing in really pushing on the limits of what games for learning can do technologically. We all know that the world of technology changes rapidly, much more rapidly than schools typically do. There are ways to use immersive technologies, high-end simulations, massively multiplayer environments, and many other tools to engage people in learning in new ways. These experiments can push on our definitions of digital games and the role of the player in the learning environment.

There are also many examples of games that were developed as self-contained embodiments of specific theories of instruction. This is an approach that is more similar to the work that the CATS group at UCLA is doing, or Herb Ginsburg's work that he will be presenting later today. Particularly in mathematics, we're seeing many efforts to use the structures and feedback mechanisms of games to explore whether we can move students through specific instructional experiences through game play.

However, what we've been doing with *Possible Worlds* is quite different from both of these approaches. The somewhat different task we took on was to really focus in on identifying and matching up the affordances of gaming to specific, present challenges that are familiar to teachers. This is the starting part for what is sometimes called design-based research – beginning with a felt, urgent problem or practice in the field. This approach is very consistent with our own history.

I want to take a sidebar here and talk for just a minute about why we took this approach, and how it is consistent with CCT's history. We've been exploring how new technologies might best support and deepen what's happening in classrooms for about thirty years. Now digital games really do have some distinctive and exciting affordances – specific things that they do well that we can all take advantage of. But this was true of the Internet, too, and laptop computers, and programming languages, and a host of other technological innovations, each of which was expected to have some kind of profound impact on education. So over the years, what we see over and over again is that we make so many of these beautiful artifacts that are incredibly designed to support amazing learning experiences. But they aren't designed to connect to everything else that's already happening in the classroom, and they aren't designed to respond to needs that teachers recognize, so they don't gain traction, they don't get used in classrooms, and they don't have the impact on student learning that they were intended to have.

So in this project, like many others, what we try to do at CCT is to be a bit more modest, and to worry less about catalyzing broad changes in education with any given technological advance. Instead, we try to focus on getting concrete – what affordances of this tool might match up well with what particular challenges exist in everyday classrooms? What is hard to teach, what particular developmental needs do students bring to a topic at a particular age? What resources are hard to gain access to, what is hard to do with students in a typical classroom that might be richer, deeper, or easier to do with a particular technological tool in hand? *Possible Worlds* is our way of asking these kinds of questions about digital games.

So what we've done is to begin by trying to identify this intersection among three factors:

1. To look at specific technologies that we can make work relative to existing classrooms;
2. To use those technologies to support and enhance instructional practice that is already in place, at moments or places where teachers recognize that they need and want help; and
3. To address learning outcomes that are really hard to achieve.

There are lots of ways to teach some things at some grade levels. Other topics are chronically difficult for teachers to tackle, despite the availability of a range of instructional resources. There are usually good reasons why these topics are hard to teach and hard to learn, and we have to think carefully about what those challenges are and how they might, or might not, match up with what a particular kind of digital resource might be good at providing. So we're trying to ask whether we can find an approach that will work, logistically, to address a challenge that really matters, with teachers who will recognize that they need and want help, that they want to improve their students' understanding.

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We put three stakes in the ground as our initial premises for the project – three ways we would begin to address these challenges we had set for ourselves. First, we focused on *portable technologies*, which five years ago meant the Nintendo DSi. Now, we're in a period of significant flux, and it's hard to tell exactly which portable device might come to be dominant for students. But at the time it was the DS – it's a great little machine, it can do a lot, it costs all of about $129, and it had a massive installed base. The DS has aged down since then – when we started, you would have bought a DS for your seventh grader for Christmas, but now you're likely to buy it for your kindergartener. But we did develop three of our four games for the DS, though we're now moving the fourth game to Flash, and refactoring the other games for tablets and touch screens through our SBIR funding and hopefully some other mechanisms. But in all of the field tests and so on that I'll be talking about today, kids have been using the Nintendo DSi.

Second, we focused on *middle grades physical and life sciences*, and specifically on "*scientific misconceptions*." I put scientific misconceptions in scare quotes here to indicate that this is a topic that deserves a whole talk of its own – I'm aware that there is a whole literature about exactly what constitutes a misconception, and it's probably true that this isn't even the right term to use here. But for the moment I'll simply call them by that name, and say that what we mean here is some of the classic examples of natural phenomena that are particularly hard to understand in an accurate scientific way, because what's actually happening is profoundly non-intuitive from the perspective of our lived, empirical experience of that phenomenon.

So why did we focus on these concepts at this particular grade level? First, we did this simply because these topics are so hard to teach successfully. As Cornelia noted in the video, they're clearly an area where teachers need some help, and if we can move the needle on these, we can be confident that we've got something in this particular use model we're trying out. Second, these topics match well to one of the core characteristics of gaming, because, if we follow on work done by Micki Chi and Jim Slotta and others, what's really hard about these topics is that truly understanding them, when they're explained to us, is impossible because we simply don't have a category available to us that can contain the idea that's being communicated. When someone tells us that electricity "flows" through a wire, but it's not a substance – what does that even mean? What we do, it turns out, is we hold onto whatever part of the concept we can match up with an existing ontological category – a group of "kinds of things" that can hold some, inaccurate, version of the concept. So instead of grouping electricity as "a thing that acts like water in many ways but isn't a substance" – an ontological category we don't have – we simplify it and stick it in there with water. Then we reason about it as if it were water, and consequently draw many inaccurate conclusions – we hold a misconception.

Games can help address this because they can help us to invest a new ontological category relatively easily. They can do this because a major attraction of gaming is that we expect it to invite us into novel, unpredictable, and even tricky or confusing new contexts. We expect games to ask us to explore new systems – to learn new dynamics that don't necessarily match up with our prior experience of "real life."

Most importantly, though, we focused on these topics at this grade level for developmental reasons. Cornelia and I are both developmental psychologists, and CCT's work has always had a strong developmental perspective behind it. We focused on this age group because early adolescence is a time when young people are just beginning to be capable of abstracting out and reflecting on their own conceptual knowledge, to identify evidence out in the world, and to organize and reflect on the relationship between their own knowledge, their own conceptual frameworks, and the evidence available to them. Now we know, from people like Alison Gopnik, that children are capable of much more sophisticated meta-cognition and scientific reasoning in general than we once thought they were. But it's at this later stage, at the beginning of adolescence, that kids become able to really consciously take control of and manage those functions, not simply draw on them to perform specific tasks or make specific decisions. Deanna Kuhn, whose work we have also drawn on extensively, writes really beautifully about this period, when kids are coming into these enormous new capacities, which need to be rehearsed and cultivated and practiced, but are also becoming increasingly able to choose not to do precisely those activities that would help them to cultivate these powerful forms of scientific reasoning.

So by tackling scientific misconceptions at this point, we are hoping to give kids compelling reasons to practice those forms of cognitive reflection, looking at evidence and relating it to existing conceptual structures that they already have and adapting them in response to new evidence. This is a difficult process in general, and the process of revising one's conceptual models of these classic phenomena is a great place to rehearse it.

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What does this end up looking like? First – game play becomes homework. We take it out of the core instructional time of the classroom, and make it something that kids do on their own time. The portable technology makes this possible, and it preserves the play as play – it's something kids can do on the bus, at each other's houses, on the couch, in the cafeteria.

One reason this approach was important to use was because it addresses an issue that comes up over and over again in research on technology integration in classrooms. While researchers and developers are often deeply focused on the instructional design of their tools, we've repeatedly lost track of the technological and logistical realities in schools. K-12 schools, by and large, still provide students with very limited access to up to date, functioning digital tools and to high-speed reliable Internet access. Making a digital tool part of a normal classroom period still means, in many, many places, either scheduling a move to a computer lab far in advance, shuttling many students through a few computer stations in the classroom, or some other less-than-ideal configuration. And that configuration typically is not well matched to the sequence of experiences the designers intended.

Bill Penuel, Nora Sabelli and others have being pushing researchers to attend more deeply to these kinds of issues, not just by recognizing their physical instantiations (not enough computers) but by integrating into our research the role that school and district level policy and politics play in shaping what happens in the classroom on a day to day basis. Funding decisions, bell schedules, labor contracts, and any number of other factors that seem far removed from instructional quality do impinge on – or sometimes support – teachers' efforts to teach well during core instructional time.

In this case, our approach to addressing this universe of issues was to work around it. By making game play into homework, we removed it from the school day and put the technological component of the instructional sequence literally in the kids' hands. Of course, this move did intersect with school and district policy in that it involved handing out handheld digital devices to hundreds of middle school students. But so far, we've encountered no problems with parents or administrations questioning this aspect of the project – although of course, that's in part a reflection of the kinds of districts that have welcomed us into their schools.

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So in addition to being homework, game play is something that kids do *before* the target concepts are covered by their teacher. We know that learning anything difficult doesn't happen all at once – a teacher can't just deliver the knowledge and expect it be absorbed and mastered by students. Instead, students need to encounter new ideas in multiple ways, and in multiple formats, over time, iterating on their knowledge and building and deepening their understanding. So teachers tend to be very thoughtful about matching educational resources to moments in an instructional *sequence* – what experiences do my students need to have at *this* point in the learning process? How can different kinds of learning experiences build on one another?

Because we wanted our games to help teachers tackle topics that are chronically difficult to teach, we had to think carefully about where our games might fit in an instructional sequence. What moment in that series of instructional experiences did we want to address?

We realized that what a game can be good at is inviting students to engage with an experience, or a concept, or a phenomenon, that is brand new to them, and possibly is also surprising, non-intuitive or novel. That's what kids expect of games – unlike typical classroom activities, kids come to games expecting to face the unexpected and to need to decipher a new environment and a new set of strategies.

So rather than providing the instruction itself, as many educational games are intended to do, or acting as a consolidation or reinforcement activity, as many teachers often use games, these games are intended to be a *pre*-instructional experience. They provide students with a shared experience, which they've hopefully spent enough time with that they know the core mechanics well. These core mechanics are carefully aligned with the core concepts the students' teacher will be trying to teach. So in this way, we're trying to use games to set up what Dan Schwartz calls "preparation for future learning" – an intentionally-designed, shared experience that can act as a jumping off point for discussion of the new concept. This fits with our focus on misconceptions, which we understand to be difficult precisely because students usually do *not* have a shared experience that maps well to the target concept. The *Possible Worlds* games are designed to insert into this role – to become the shared experience that teachers can harvest as they introduce students to new, relatively abstract scientific concepts.

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And finally, the *Possible Worlds* games play a more specific pre-instructional role – they act as grounds for analogical reasoning about these target scientific concepts. This builds on work by Derdre Gentner, who has demonstrated in detail how well-structured analogies can scaffold students' thinking. This is why we're able to create games that do not present content, or hold students accountable for mastering anything other than the internal logic of the game. By playing the game, we hope, they are instead getting a secure hold on a core game mechanic that has an analogical relationship to the target concept. Keith Holyoak has pointed out how important this repeated exposure, mastery and internalization of the source for the analogy is. With support, it's our hope that teachers can harvest that experience, now shared by their students, to help students think through the dynamics of a new, unfamiliar, and otherwise counterintuitive phenomenon, with reference to the dynamics of the game the students played as homework the night before.

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So those are the key characteristics of the game's relationship to learning. Drawing on that framework, we structured an instructional sequence that acts as a three-part supplement to teachers' normal instruction. Over the past four years we've now created four of these modules, which we intend for teachers to use as a supplement to their normal coverage of these concepts.

What does this look like in practice? First, teachers have kids play the games as homework prior to beginning their normal unit.

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Then teachers move through their normal coverage of the topic, adding several activities that we designed to support them in leveraging the analogy provided by the game.

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The final step is a consolidation activity that asks students to use what they've just learned to try to disprove claims made in fantastic-sounding articles about scientific discoveries.

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So these are the modules we've been creating and trying out with teachers and students over the past several years. I'm not going to go into detail about the various kinds of field tests and other studies we've been conducting. Rather, I'd like to just give you a broad overview of the kinds of findings that are emerging from this work. These map back to the three big questions that we began with – questions about whether we can make games that *enhance* existing instruction, contribute to an interactive instructional *process*, and help students master some of the hardest-to-teach concepts in middle grade science.

First, we've tried to manage the logistical and hardware dimensions of the project in a way that allow the games to *enhance* instruction by not *displacing* instruction, but making digital game play a homework activity. So we've needed to ask some very practical questions about the feasibility of this model. Can it work? The evidence we've collected about this dimension of the project really tells the simplest story of all, which is that this has worked, quite clearly. We've now handed DS or DSi game machines out to about 1,200 students. They've been asked to use them to play specific games at home and to return them after several days. We've had almost no loss or damage of the machines, and we've had no conflicts or problems with teachers or administrators, or any reports of problems among kids about the DSs.

Further, the evidence so far tells us that the kids are playing the games. In our largest study, looking at the impact of the photosynthesis module on student learning, we asked students to play for half an hour over the course of two days. Kids actually played an average of about 42 minutes, and girls played about six minutes longer than boys, on average. This gender difference is particularly important because boys still tend to be more enthusiastic and experienced gamers than girls, and we made an effort to design games that would appeal to both boys and girls. So it was good news to see that girls are in fact playing when we ask them to.

That said, as I mentioned earlier, the DS is aging down, and cell phones and tablets now seem to be a more viable way to put digital games in kids hands outside of the classroom. Through several avenues, we are working on porting all of the games over to tablets, but all the research discussed here is based on kids playing on the Nintendo DSi.

The second question is really the teaching question. Does this pre-instructional model work for teachers? This turns out to be a more complicated story. We're finding that making really productive use of the game as a source for analogical reasoning is more challenging for teachers than we had expected, for a range of reasons. First and most basically, teachers are not typically playing the games themselves. This means the games remain a black box to them – shared by the students but untapped by the teachers. Interestingly, in Dan Schwartz's work it appears that this may be enough – he does not discuss in any detail how pre-instructional experience might best be mined to support learning during normal instruction, when the teacher is "delivering" content or key concepts. But others do provide guidance on what it takes to activate or leverage an analogical source – Lindsay Richland, for one, has looked systematically at video of teachers using analogies to structure their teaching and has isolated specific teaching moves that seem to make analogies most productive for students. In the future we will need to weave more explicit guidance for teachers into our materials to help them determine when and how to make reference to the games and map their core analogies to the target concepts.

When teachers do make explicit reference to the games during instruction, we're finding they do not necessarily use them as analogical grounds at all. Rather, teachers often reference the games as an *example* of the concept they're discussing. While this may appear to be very similar to our intended structure, it's actually quite different, as it depends on students holding the new concept in mind (which they are unlikely to be able to do yet) and trying to map it back to the certain features game mechanic, rather than the other way around. This is going to be difficult for them because without the new concept in mind, they have no way of knowing what features of the game their teacher might be referencing as an analogy.

Finally, of course, we are beginning to ask questions about the impact of these modules on student outcomes. We conducted an experimental trial of the first module during the 2011-12 school year, and we're analyzing those data now. That trial involves 41 teachers and about 950 students. We created an outcome measure with 36 items that is intended to probe students' conceptual understanding of photosynthesis and the chemical change processes underlying it.

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While of course we're very hopeful about the results of the experimental trial, we also carried out another assessment study that I think will, in some ways, be even more interesting. As we know, it's often easier to find an impact on student learning when you're measuring that impact right after kids have finished covering a topic, when it's fresh in their minds. It's much harder to have an influence on their long-term understanding of a topic. But if our model works, it's possible that we could achieve a long-term impact, because our goal has been to give kids the tools they need to build robust conceptual models, and compelling reference points for those models that they could potentially hold onto over time.

So, to check on this possibility, we identified a set of classrooms that had covered photosynthesis in October – both groups that had used the *Possible Worlds* materials and ones that had been control classrooms for the study. We went back to these classrooms in May and June of 2012, very late in the school year, and six months after kids had been exposed to this content in class. We conducted one-on-one interviews with about 35 students, and we asked them a version of the classic question that exposes some of the common misconceptions about photosynthesis – "where did most of the weight of a sequoia tree come from?" Now in case you're not really up to date on photosynthesis – the correct answer here is "carbon dioxide," because it's the molecule that makes up most of the weight of glucose – which is the thing that plants make, using sunlight for energy, out of water and carbon dioxide that they draw out of the air. Too often, both children and adults' answers to this question reference soil, and assert in one way or another that plants "suck up" or "eat" soil and somehow convert it into plant matter.

We haven't finished looking at these interview data yet. But we had some very compelling interviews with students, and I'm going to close with two examples, which I'm shamelessly cherry-picking to suggest the kinds of differences we are seeing between our samples at least in some cases.

This first child was from a class that did not use the *Possible Worlds* materials. What's interesting to note about his explanation is that he is using an analogy – he's trying to explain where a tree comes from referencing something else that he knows. But in this case his reference is to fungus, which unfortunately does not grow in the same way that trees and other photosynthesizing plants do.

The second student was in a class that did use *Possible Worlds*. Her response is very representative of what we would hope a seventh grader could explain about photosynthesis – she knows what the inputs are, that they are recombined on a molecular level, and that they're recombined to produce glucose, which then serves as both an energy source and a building block for producing new plant material.

Whether or not our impact studies demonstrate a clear and simple impact of *Possible Worlds* on student understanding, our research to date has already provided us with a lot of insight into both what's most promising about this approach and what we'll have to continue to refine. Just as importantly, it's given us a rich opportunity to look carefully at how middle grade students try to make sense of some of the highly abstract, complex systems they are expected to learn about in the middle grades. We are hopeful that the

Possible Worlds games can provide them with playful, compelling, and memorable concepts that can support them in building robust, accurate new scientific knowledge.

For more information about *Possible Worlds*, please view our video on YouTube. Search for "EDC Possible Worlds"
or visit CCT's website for updates on all of our project work: cct.edc.org
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