Repurposing everyday technologies for math and science inquiry

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Abstract: Students often have far more sophisticated scientific instruments in their pockets than in their physics classrooms. Today's cell phones and game controllers offer sensors, cameras and communication technologies that can be used for in-depth exploration of physical phenomena. Because everyday toys and tools offer connections to children's social worlds, they are particularly useful for integrating classroom science with everyday intuitions and experiences. Drawing on data from a multi-year research project to help children hack gaming technologies for science inquiry, we examine both technological and social advantages that repurposing everyday technologies for offers for learning abstract STEM concepts. In light of trends towards increased decentralization of education, we extend these findings into a general discussion of the potential for embedding CSCL into the design of everyday things.

Introduction

In many communities kids live and grow in social worlds embedded with interactive technologies of a potency rarely found in classrooms. Sensors in toys, computers, and phones capture changes in position, direction, acceleration, location, and proximity; data streams seamlessly between devices; screens, lights, and audio represent this data locally or remotely. Together, these technologies enable more of us to spend increasing amounts of time learning outside of schools. However, they also offer deep, yet often hidden, affordances useful for classrooms. Even moderately-priced cell phones, game controllers, stuffed toys, watches, handheld computers and workout equipment contain sensing technologies—such as accelerometers and infrared cameras-—that could be tapped to reveal the science and mathematics that underlie and describe the workings of the physical world. Because these objects are in everyday use, they also hold the potential to bring difficult concepts in math and science into children's day-to-day social contexts.

A handheld game controller is one such an inexpensive everyday device with components that lend themselves readily to math and science inquiry. The Wii Playstation Remote, which features a three-axis accelerometer, a gyroscope, an infrared camera, seven buttons, a speaker, a haptic motor and two-way wireless Bluetooth communication, cost less than $20 USD at the time of writing. Affordable, powerful and hackable, they are also pervasive in many children's social worlds. (Nintendo's survey data indicates 46% of Americans aged 6 to 74 played a Wii or Nintendo DS in 2010 (Iwata, 2010).) Components in these devices measure physical phenomena related to motion, such as distance, rotation, velocity and acceleration, common topics of study in science classrooms. Given its ubiquity, the Wii Remote and devices like it could be as familiar and as ready at hand for physics projects as a desk ruler.

Numerous teachers, researchers, hackers and DIY enthusiasts have written about hacking game controllers for learning in various contexts (Williams & Rosner, 2010; Lee, 2008; Hill, 2009; Pearson & Bailey, 2007; De Bruyn, 2008; Graves et al., 2007). Perhaps closest to our work, researchers focusing on high school and college-level physics curriculum (e.g., Vannoni & Straulino, 2009; Somers, et al., 2009; Wheeler, 2011) used game controllers to collect data related to phenomena such as the motion of a pendulum, simple harmonic motion in a spring, and linear displacement on a track. Inspired by this work and interested in bridging the gap between 'hands on' project based learning and abstract concepts presented in lectures in middle school science classrooms, we launched a multiyear research project to engage children in hacking game controllers to collect and visualize data related to their design projects (described in detail in Lewis, Acholonu & Ju, 2012). We anticipated that children would glean data from their projects and—perhaps more importantly—that they also would gain a better sense of how physics and math relate to the technologies in their everyday lives.

Throughout the course of the project, we noted consistent talk anchored around the device that traversed boundaries between children's 'social worlds' of gaming and their classroom 'science worlds.' In this paper we briefly provide a description of activities with students, and then present snippets of classroom interaction that exemplify the overall *technological* and *social* affordances that contribute to the blending of these worlds. We conclude with larger questions for CSCL about how the commonplace "smart" devices of childhood might contribute to math and science learning across contexts. Currently everyday technologies are designed to be easy to use, their very form factor inviting the user how to learn to manipulate them to accomplish a goal (Norman, 2002). We suggest that, with more people learning in distributed, informal contexts, the technologies around us, such as cell phones, depth cameras, GPS technologies, and other sensor-driven personal devices, might be altered to lead people toward learning not only *how to* accomplish something, but also toward more fundamental principles about *why* the world and its technology works as it does.

Project Overview

The interactions presented below are from a three-year design experiment (Brown, 1992) to develop software and curricular tools to support the use of game controllers and mobile phones as inexpensive data acquisition tools for middle-school-level physics activities. The design research (Edelson, 2002) goals of this project are twofold: 1) to design activities and software to help students and teachers harness everyday technologies to support scientific inquiry in science classroom labs and projects and, more broadly, 2) to develop activities and software tools that encourage young people to repurpose these same technologies for their own interests and pursuits in and out of school. In the spirit of participatory design, the project was carried out in close collaboration with the faculty and students of our partner school, with the participants considered co-designers of the overall program. Researchers programmed the software and ran classroom activities, soliciting suggestions and feedback for both. We refined designs in response to faculty and student input, as well as our own observations of our program's impact on classroom dynamics and learning. This cooperative design approach is similar to participatory and collaborative approaches outlined by Inkpen (1999), Druin (1999), and others working in the realm of classroom technology research and design (Rode 2003).

Setting and participants

All activities took place in a 'constructivist' sixth-grade physics class at a private school for academically talented students. The physics teacher was experienced at leading project-based activities, and alternated between open-ended design projects, structured labs, and direct instruction, usually presenting abstract concepts, algebraic formulas and graphical representations of data via interactive lectures only after related hands-on projects. This site was chosen because of its instructional philosophy, because of its commitment to innovation, and because the school issues and supports Apple laptops to all middle school students, enabling teams to easily use the software we provided.

One hundred and eighteen sixth-grade boys and girls, in three classes per year over two years, worked with us on this project. Overall, students drew upon high levels of technological experience, with several bringing engineering and programming skills from robotics clubs or mobile app programming classes. Surveys indicated most had extensive experience with a variety of computational devices, with all having access to or familiarity with computer and video game technologies at home.

Activities

Four hands-on activities with gaming technology were conducted during the course of each school year, all of which were video recorded. After each activity as many teams as possible were interviewed using "artifact based" techniques (Barron 2002). Students used two emerging interfaces that either harnessed data from the force sensor, showing graphs of changing acceleration over time, or tracked the position and duration of interruption of infrared lights aligned with the game controllers IR camera.

To engage students in a common experience and to better understand their prior knowledge, the project started with a warm up activity that involved playing the "Wii Tennis" game in small groups, and followed by group discussion on how they thought it worked. This was followed by a three-week "mousetrap car" design activity (Figure 1) a fun project often conducted in middle school science classrooms. In this activity students are tasked with designing and building a car powered by a mousetrap. They tinker with materials and their naive understandings of the physics of motion to develop an efficient car with maximum acceleration that will travel as far as possible under its own power. In the course of the project, students encounter concepts related to forces, such as friction, mass, velocity and acceleration. Students strapped game controllers onto their cars to visualize changes in acceleration over time and relate those to design factors. Some students disassembled the game controllers to make them lighter. The classroom teacher followed up this activity with students presenting and discussing their findings before offering several direct instruction sessions on Newton's laws of motion.

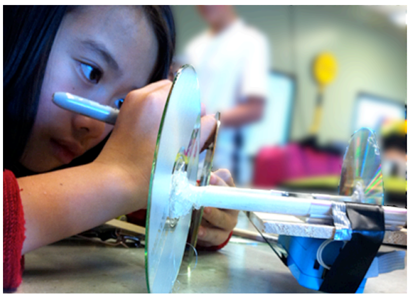

Figure 1. Students mousetrap car with WiiMote suspended from chassis.

Noting conceptual issues related to "negative acceleration" in students' explanations of their mousetrap cars, researchers next presented students with a "punch" activity. Students were asked to predict the "shape" of the acceleration graph of a single, extended punch and test their prediction over multiple trials. Students drew their predictions on paper, and then, in groups of two, recorded their trials using camera phones. Holding a string tied to a vertically suspended game controller (Figure 2), students punched and examined the line graph of change in acceleration over time. Results were reported out, which led to a group discussion of 'negative acceleration.'

Figure 2. Students punch and watch the screen to explore negative acceleration.

The school year concluded with a marble rollercoaster activity, also a common project in middle school science classrooms. Studying kinetic and potential energy, students built a marble rollercoaster (Figure 3) within specified constraints. Using their knowledge of the workings of the gaming system, and infrared LEDs and IR cameras from game controllers, they developed systems to track the marbles velocity at different points along the track.

Figure 3. Students aligning IR light with Wii IR camera on their rollercoaster track.

Findings

We found it notable that some of the most productive discussions involved students not simply analyzing their team's data, but talking more broadly in conversations that forged a three-way link between the principles of physics under study, the technical functioning of the game controllers components, and the social context of gaming. The illustrative snippets below were taken from video of classroom activities and post activity interviews across two years of the project. As a whole, they suggest that the gaming origins of the technology made a difference in how students participated in and talked about what they were doing in the classroom. This influence is subtle and likely would have gone unnoticed except that it showed up on tape repeatedly across classes, and often during gaps between more formally organized activities – such as during set up or testing of technology as students were preparing to use the remotes in their projects. Classroom video was revisited and coded for general reference to physics and the technology. Excerpts that contained direct references to *gaming* were further coded, revealing six general ways repurposing helped link children's social and scientific worlds.

Linking technological affordances to core concepts in science

The tools used in these activities are ultimately useful because of the inherent deep connections between the core functions of game controller components, the action on screen, and core curricular concepts. For example, the force sensors in handheld game controllers such as the Wii Remote measure acceleration across three axes, and take into account the force of gravity. Core mathematics skills involving graphing, algebraic functions, and the mathematics of change are deeply connected to the data stream the game controllers emit, as are core concepts in physics such as position, velocity, and positive and negative acceleration.

Most importantly, this data stream is accessible and flexible. It can be harvested and interpreted according to students' learning contexts, and readily pairs with their own laptops or other Bluetooth-enabled devices. While commercially available demonstration cars and other pre-formulated technologies display data related to force and acceleration, this technology is expensive (at the time of writing, approximately $400 per car) and its display output is limited. Data cannot be saved, aggregated or easily shared. By harvesting data from the game controllers, we are not only able to use custom data visualizations to directly address issues students were struggling with, but also take advantage of hidden 'hooks' into the curriculum. For example, gravity is a difficult concept in part because unless something is falling, students don't 'see' it in action. Even after studying gravitational force, students often base their explanations on their everyday intuitions that gravity is something that 'happens' when you drop something. The force sensor in the game controller measures gravity along the Z-axis, of course whether or not the device is moving. The following vignette illustrates how this offers an accidental learning opportunity. In the interaction below, one student, while pairing the Wii remote with his computer for the mousetrap car activity, noticed a line marking "1" along the Z axis:

> Student 1 (assuming he had paired with another team's Wii): "But I'm not moving it. Why does it say one? Wait, stop shaking the table. Maybe that is someone else's?"
> Student 2 (grabbing the Wii and shaking it): "No. Look!"
> Student 1: "It's stuck… no…"
> Teacher (passing by): "You aren't touching it, but are any forces acting on it?"
> Student 2: (after some time playing to figure out what the Z axis represented): "Gravity?"
> Student 2: "No, but it's not falling …"
> Teacher (swinging the Wii like a tennis racquet): "Ok. The force sensor measures the force you move it with, so it can know how hard you hit it but also any other forces acting on it. Is gravity acting on it right now? … What else is acting on it? Why isn't it falling?…

This interaction lead to a rich discussion of the force of the table exerted on the device, the general concept of the 'normal force,' and to how the Wii tennis game takes gravity into account. Exploration with the tool and a mathematical representation of its data stream led students towards exploration of core ideas of physics and the mathematics of change.

Linking social worlds to science worlds

Certainly other technologies, such as sensors attached to Arduino boards or photogate systems described in physics education catalogs are also available and similarly useful for harvesting and representing data. Besides the convenient form factor and cost savings, what is the advantage of using everyday familiar technologies such as game controllers in classrooms? While visualizations of the output of the technology's components led students toward discussion related to math and science, the social gaming context of the device led to students forging connections across contexts that we think led to further encounters with these ideas in action in their everyday lives. The choice to repurpose a well-known game controller as the device to reveal data related to force, acceleration, and velocity mattered to students' interactions. We have observed that while the activities themselves presented students with data, graphs, and 'discrepant events' (Nussbaum & Novick, 1982) that helped them confront and develop their lay opinions and intuitions about physics, often *the way* in which they came to interpret these events was by synthesizing their new observations with their prior experiences of using the technology for gaming. This cross-contextual synthesis appears to have played a role in students' everyday thinking with scientific principles. The following general categories emerged as relevant to the value of the 'everydayness' of these tools for math and science learning.

Expertise is connected to 'felt' experiences and intuitions

Students' experiences with game controllers are for the most part felt experiences; they learn to swing an on-screen tennis racquet by feeling the relationship between the motion of the controller in their hand and the visual feedback they receive onscreen. Through felt experiences they develop intuitions about the way the game works as well as the way the Wii Remote works. For example, in Wii gaming, expert players often make only small, quick movements with the device, rather than the broad sweeping strokes of a novice swinging an on screen racquet. While experienced players have a felt sense of the difference, they often don't "know" why their techniques work. This presents rich fodder for discussions that link everyday intuitions and experiences with core principles:

> Student: "No, it's like (flicking the Wii remote and pointing to the screen that shows a graph of change in acceleration over time)… it's not how far. It's like how much it's changing … see… (moving hand steadily at a constant rate, producing a relatively flat line). See… cause it's flat… cause it's not changing it's just moving steady. Like when you swing… you know you can just go… (flicks it again, causing a sharp peak on screen) … 'cause it's not how big the swing is, it's just like, how hard you do it, how quick (flicking several times). Like, I mean in tennis, if you know what you're doing you just flick it to hit it hard."

Ready at hand, easy to use, and draws on familiar metaphors

Gaming technologies have been designed to be ready at hand for students' play. They are easy to set up, easy to use, easy to remember. Students feel they "know" them, and are not concerned with breaking them or worried about learning anything new to set them up. Because of their prior experiences, in general students had an orientation towards efficient set up and troubleshooting. Generally, their familiarity with the metaphors of 'pairing' and 'sensing' provided anchors for getting everyone on board. However, some metaphors provided fodder for rich discussion when they broke down. Although facilitating the practical set up of a game console, some terms, like 'sensor bar,' are misleading when it comes to science and engineering. Discussion of the 'sensor bar' provided an opportunity to analyze not only how the game worked, but the forces at play in its marketing:

> Instructor: "So, what is this?"
> Students: "A sensor bar!"
> Instructor: "Sensor? What does it sense?"
> Student 1: "LEDs."
> Student 2: "Like, the position of the Wii thing."
> Instructor: "So, where is the LED?"
> Student 3 (eventually, after some disagreement): "In the sensor bar!"
> Instructor: "Ok, in the 'sensor bar.' So where is the sensor?"
> Student 1: "In the Wii!"
> Instructor: "So, there is a camera in the Wii remote, and infra red LEDs in the 'sensor bar.' Why do you think Nintendo calls it a sensor bar?"

While generally the culture of gaming provided analogies for students to draw on in their learning of physics, in this case, terms used in the culture of Wii gaming obfuscated the functionality of the device. Metaphors, as cultural tools, needed to be explicitly redefined in order for students to understand how the game and the photo gate system worked. The students agreed to use the term "LED bar" in class rather than sensor bar. Several students reported telling their friends outside of school not to call it a sensor bar as well, thus bringing ideas from class back into a gaming context.

Socially situated and meaningful to students' interests

Handheld game controllers are 'social' tools that students use in groups. They are closely connected to the interests and concerns of students, and students spend a great deal of time learning the values and culture of game play from each other. This gives them a positive social valence and connects 'science' to students' social worlds outside of school. Availability in out-of-school times and contexts helps blur the boundaries between learning and play; students can hack their game controllers at home as well as at school. For those with strong interests in gaming (or hacking), this can lead to discussions of the math or science of game controllers with parents and friends in multiple contexts.

While most gaming is social, 'embodied' gaming via handheld game controllers is perhaps more social than most. Students move dynamically in teams, often in direct or peripheral physical contact with each other. They value being able to play well, and keep track of details of set up, scoring points, and techniques that show expertise. In classroom conversations we found this sociality bled into physics talk – students frequently referenced or mimed game play in the classroom while talking about science. In addition, students reported talking about science with siblings, parents and friends while setting up or playing the game at home. This blurring of boundaries between students' social and scientific worlds we think is likely productive for future learning. If knowing the science behind gaming devices becomes part of their gaming cultures, students may be more likely to integrate science into their everyday worlds and future plans. Examples of this blurring of boundaries of time, place and social context show up repeatedly in video recordings of students' talk in class. Two examples:

> Student: "Hey, maybe we could all come over to my house. I have a big TV and I live just over there. We could bring science class over and we could like, do Wii gaming and stuff at home after school. 'Cause we'd have more time and it would be more fun to, you know, do it outside of here."
> Researcher: "That's an interesting idea. We could do some things after school here if you think kids would like that."
> Student: "Yeah, but at home we have snacks and my other friends could come. It would be more fun."
>
> Student: (smiling) "Hey, you guys kind of ruined the game for me. …"

> Researcher: “Why?”
> Student: “Because now every time I swing, its like I don’t really see the racquet move, I see acceleration in my mind. Like, I swing to hit the ball, but in my head a graph shows up. It’s really distracting. And, like, my friends don’t really want to hear all about acceleration when they’re playing.”
> Researcher: “Do you talk about it with your friends?”
> Student: “Well, I showed them on the laptop what we were doing and we played… They [thought it was] cool, like, that I could connect it to my laptop.”

Event based and therefore evocative of storytelling

Things ‘happen’ in games. Games have beginnings, middles, ends, as well as heroes and heroines. Experiences of gaming are memorable and get repeated in stories of great achievements and defeats. Students draw on these stories and memories of past experiences when encountering the technology in new contexts, providing rich fodder as supporting analogies for learning.

In the classroom, students told stories about their gaming achievements and adventures, occasionally reinterpreting them using concepts they are learning in science class. These stories served as cultural resources, so that the gaming technology supporting not only the goal of activity, but also ongoing cultural change as dramatic stories played a role in knitting together students’ social memories and emerging understandings.

> Student: “One time, when I was beating my brother, he came after me and threw it at my head. But, like when he did that, it whizzed across the room but in the right time, so like on the screen he scored the winning shot. My family always jokes about that… he had to throw it at me to win. I guess it, like, accelerated just right?”

Elicits more general ‘imagineering’

The act of repurposing itself is an inventive and creative act. It requires the re-envisioning of one thing for completely new purposes. This kind of deconstructive and reconstructive thinking often leads to further episodes of ‘imagineering’ and design. Because the project-based classroom we were working in had a focus on design, we conducted several brainstorming sessions with students, asking them to invent other ways they could use the technology for their own ends. Students came up with creative answers such as using the IR camera for a “mom detector,” an “automated pet feeding mechanism,” and a “Halloween candy counter.” They used the accelerometer to design a means of determining a pet’s activity level, and a “little brother running in the house” alarm, etc. Several technically minded students rewrote sections of our code to change the interface, and got intrigued with the practical possibilities for building some of these ‘imagineered’ designs. Sometimes students expressed changing identities in relation to imagineering. For example, in a casual debriefing interview toward the end of the school year, a student was asked what she learned:

> Student (laughs teasingly)…: well… to play the game better!
> Researcher (teasing): “Well, at least something we did together was useful then…”
> Student: Well, really I wasn’t into it. I wasn’t very good before. At tennis, I mean… (long pause)… I think I’ll make a game one day. Do you know the light saber one?”
> Researcher: (shakes head no)
> Student: “I found it online. Like… well you can pair your Wii remote to this game a guy made. Then your Wii acts like a light saber. It’s.. well real simple… like someone just made it. You don’t have to be a big company, really, if you have you know, the stuff. I mean, if you know how to get into it… and anyone can download it online for free.”

Reveals everyday invisible processes/ data

Games rely on the interpretation of a data stream to construct visualizations that enable play. Students who hack gaming technology gain an understanding of what data is, how it is useful, and why it’s valuable to be able to collect lots of it over time. They start to ‘see’ the data that drives much of the technology that makes up their mediated worlds, and through looking at the computer code that processes it, start to understand why digital things look and act the way they do. One simple example among many: A student asked, “So, what about the remote control to my TV? Is that Bluetooth too? And what is it sending… like a number or something for the computer in the TV to change the channel?”

Discussion

These interactions illustrate why, in certain contexts, repurposing everyday devices for science and math learning may make more sense than using specialized, unfamiliar technologies. This may be particularly true for middle school age children, who generally are constructing and asserting both social and academic/

mathematical/scientific identities that carry through into their high school years. By bringing artifacts and context from children's social worlds into the classroom, we are able to draw on their interests, cultural supports and expertise to support inquiry. Of course, in so doing children begin to construct new cultural experiences, ones imbued with science, that also spill over into their social worlds outside of school. Not only does harnessing familiar technologies offer students opportunities to informally synthesize prior experiences, but it also offers them 'prior' experiences to draw upon when they next encounter the tool in a gaming context. Tapping into the game controller as a cultural as well as scientific tool offers cultural groundings for the scientific understanding of future informal gaming experiences. While the one student joked that we "ruined" the game for him, his experiences appear to have opened up, or perhaps reinforced, pathways towards a socially supported identity as not only a gamer, but also as someone who knows science and knows how to code.

For those interested in learning design for CSCL, this raises questions about the plethora of devices beyond game controllers that technological affordances and hold potential for tapping into social contexts to support children's exploration of fundamental STEM concepts. With what supports and interfaces, and in what contexts, could other everyday data-enabled devices be positioned to make science concepts more "culturally available" (Roth, 1994, 1999) in everyday experience? Our study of learning with game controllers indicated that several factors might be worth noting when considering harnessing other everyday technologies for learning. Engaging with tools that are socially situated, that tap into felt experiences, that draw upon prior technical expertise and narratives, that bring hidden processes to light and that call these into future possibilities via 'imagineering' sketching and talk might offer children opportunities to more deeply connect their social identities with math and science.

Although this study indicates that adapting everyday technologies in the interests of math and science curricula is useful, at a technical level it isn't yet easy. It is only recently that three forces have come together to make innovation work. A growing number of manufacturers have opened up APIs to software developers, who have enthusiastically developed middleware and published "how to" videos and articles to support a more general, and growing, DIY (Do It Yourself) movement that includes creative individuals, component retail outlets, art organizations, and tech enthusiasts. Open scripting languages such as Processing that facilitate the rapid generation of code have helped interested people develop useful software quickly and inexpensively. Even more critical, easily downloaded middleware such as "Osculator," has enabled Bluetooth pairing of Wii Remotes to a computer so data is accessible.

While these efforts have launched a hacking movement that has started to be picked up by teachers, there is still little ongoing communication between classroom teachers and those enthusiasts who are developing tools that make everyday devices accessible. Having spent several years conducting these activities in classrooms with teachers and students, we would like to suggest that applying learning design, and not just usability design, would help make it easier for classroom teachers to take advantage of the technologies that are available in the interests of math and science. Several basic technical design considerations would be helpful for supporting learning. Among these of course include prioritizing social and collaborative features; building with transparency in mind; bringing cultures of science (terms, metaphors and analogies) into 'play' to map affordances to core science and math concepts; and offering alternative interfaces to support multiple representations of data, from game characters in motion to graphs that represent change over time.

Conclusion

One of the major struggles in science education is creating contexts in which all students, regardless of gender or social background, can see themselves as connected to science. Facilitating "science talk" (Lemke, 1990) and "transformative conversations" (Polman & Pea, 2001) in everyday interaction can help students forge an identity as investigators and inventors in science and engineering. Using gaming or other social technologies for scientific inquiry holds promise for integrating students' playful identities with their emerging identities as scientific investigators, thinkers, and inventors. In addition to integrating their social worlds into gaming, they also brought their experiences of science back into their social worlds. We see this as a kind of identity work by which students expand their sense of possible future selves.

We'd like to conclude by raising a large open set of possibilities for CSCL research. Computational and sensing technology is increasingly embedded in everyday items. This means that everyday items contain components with deep affordances for teaching science and mathematics. As increasing numbers of students are learning outside of school, via online courses, via their own online research, or by tinkering and hacking on their own, this raises large opportunities and questions for the field of technology design. If game controllers, with the addition of learning design interfaces, hold the possibility to lead students toward physics, what about other devices? What would a hammer look like that was not only designed for usability to be ready-at-hand for hammering, but also designed for learning about kinetic and potential energy? What if it could lead a user not only how to hammer efficiently, but reveal the fundamental principles of physics on which such motion functions? Or, what design factors could be added to a merry-go-round to help riders understand centrifugal force? What collaborative features could be built in? For DIY enthusiasts interested in learning, what interfaces and components would make everyday objects embedded in our social worlds not only usable, but deeply conceptually and socially instructional? As core education is increasingly distributed in out of school contexts, it is time to start considering how everyday things might lend themselves to teaching the fundamentals students need to know. After all, they will be using science and mathematics to invent the next, newest everyday things.

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