Using Low Cost Game Controllers to Capture Data for 6th Grade Science Labs

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ABSTRACT

This paper describes a cooperative design project to develop ways to use Nintendo Wii Remotes as inexpensive data acquisition tools for science. In collaboration with a 6th grade physics instructor and his students, we have developed software tools and curriculum that enable science teachers and students to repurpose gaming technologies to study concepts such as velocity and acceleration. The project involved a year's observation of students' project based learning in a 6th grade physics class, followed by a year of design experimentation to engage students in integrating game controllers into their projects. Using the insights from their observations and suggestions, we created three different Wii Remote-based setups that used the IR camera and the accelerometer to help students glean data from their projects. In this paper, we provide an overview of the project, and then offer data that demonstrates the added value across the material, social, experiential, and temporal aspects of inquiry science activity. We conclude by identifying key design opportunities within this space.

Author Keywords

Education, Wii, Science, Laboratory, Data Visualization, Children, Physics

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors; Design

INTRODUCTION

The proliferation of interactive devices with embedded processors, integrated sensors and wireless communication capabilities has it possible to gather sensor data from almost any object in our physical world. While designers of products often strive to have data collection, computation and transmission happen invisibly to support people's day-to-day activities, these same technologies can also be designed to bring measured data to the foreground so it can be used to gain insight on phenomena around us. One area in which this design direction is most useful is in science education.

Seeking to lower the barriers to integrating data into our everyday understanding of the world around us, we have been hijacking data from Nintendo Wii Remote game controllers for the purpose of augmenting 6th grade physics labs with visible data. The digital capture of sensor data within the context of in-class labs and projects allows students to see invisible phenomena—such as gravity and acceleration—for which it might be hard to gain an intuitive understanding. In addition, using gaming technologies for science offers the possibility for students to gain a more grounded understanding of the underlying technology and how it might be repurposed.

We hypothesize that sensor technologies found in everyday handheld items such as gaming equipment and cell phones can improve on practices in constructivist "hands-on" laboratory and project-based science learning in four key ways:

- Manipulating ideas via manipulating tools
- Supporting social interaction
- Harnessing everyday and embodied understanding
- Enabling more data, in more classrooms, more often.

The opportunities provided by introducing these new data tools to learning environments are accompanied by a host of challenges to be tackled or designed around. This paper discusses our activities in integrating Wii Remote devices into a 6th grade project based physics classroom. We describe our theoretical approach, as well as activities, findings related to the above hypothesis, and the lessons and design opportunities we encountered in the course of our multi-year engagement on the Wii Science project.

BACKGROUND

Although labs and projects are a cornerstone of modern science education, physics classrooms often lack the tools necessary for "hands on" exploration of physical phenomenon. Below we offer a review of contemporary challenges to integrating data into hands-on learning in classrooms and day-to-day experience.

Lab and Project Activities in Science Education

Hofstein and Lunetta define laboratory activities to be "learning experiences in which students interact with materials

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and/or with models to observe and understand the natural world." [12] Ideally, lab activities would help students "describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others identify their assumptions, use critical and logical thinking, and consider alternative explanations" [27].

Constructivism

Laboratory and other "hands-on" activities are of particular importance to advocates of *constructivist* models of education. Although there are different schools of thought within constructivism, generally theories are grounded in the idea that learners learn best when they are able to base their ideas and understandings on a series of personal first-hand experiences. [6][38] Over the last 20 years the turn in cognitive science toward theories of situated [11][22], embodied [21] and distributed cognition [15][30] acknowledges that much of "learning" happens not in the head, but in fact in the body and via arrangements of situations and artifacts in the world around us. Laboratory and project activities can stimulate interest in science by providing opportunities for students to pursue inquiries they have about the natural world, and by framing their prior experiences and intuitions within a more generalizable scientific understanding.

However, while many science teachers learn constructivist theories in education schools and academic researchers have run numerous studies of constructivist methods, Williams and Hmelo note that "this information has had relatively small impact on education practices. We do not, as yet, have a widely accepted theory of instruction or carefully thought out manageable methods of implementation consistent with constructivist theory." [41] Researchers have noted that often integration of new technologies offers opportunities to influence pedagogy, as they open up new practices in the classroom. [26] In the case of wireless gaming devices, we think such new practices may include more pervasive, casual or playful inquiry into everyday phenomena using data and its representations. In this sense, accessible sensors found in everyday devices such as game controllers may enable data-rich constructivist learning activities that were inaccessible without such tools.

Tools of play, tools of science

The Wii Remote's ubiquity in many countries lends it to be a viable tool for both classroom and every-day exploration. The fact that the Wii Remote is mass manufactured means that the components and their associated capabilities are remarkably cheap—at the time of this publication, a battery powered remote with a 3-axis accelerometer, a gyroscope, an infrared camera, a wireless Bluetooth receiver/transmitter as well as seven buttons, a speaker and a pager motor cost less than $30 USD. More importantly, for many children, the Wii Playstation is an everyday household device—Nintendo's survey data indicates 46% of Americans aged 6 to 74 played a Wii or Nintendo DS in the past year [18]—which means that, given well designed software to access its data, the Wii Remote could be for many people as familiar and as ready at hand to appropriate for spontaneous experiments as a measuring spoon. While we have chosen the Wii Remote for this work, we anticipate that the software and activities created can and will be adapted to harness a wide variety of interactive sensing devices currently being brought to market.

Wii Remotes in Education

Currently a wide array of projects are investigating educational uses of the Wii: developing the motor skills of preschoolers [3][13], supporting disabled students in education [31], teaching musical rhythm [5], and, promoting physical activity [12]. In physics, Vannoni and Straulino [39], Somers, et al. [37], and Wheeler [40] have used Wii Remotes in high school and college physics courses to analyze the motion of a pendulum, simple harmonic motion in a spring, and linear displacement on a track, respectively. These have inspired and informed our notions of what is possible in our design activities for earlier physics education.

POTENTIAL BENEFITS OF LOW-COST DATA SENSING

As a research endeavor, this project strives not just to help students learn physics or to only develop tools to support teaching physics, but also to uncover the properties of effective tools for science inquiry. In this sense we hope to inform both theories and practices of effective constructivist learning environments. Below we discuss the four areas in which we hypothesize such handheld gaming technology is well positioned to play a unique role to foster new practices in laboratory and project based learning. These span the material, social, experiential, temporal aspects of inquiry science activity, and gave focus to our design engagement.

Manipulating ideas via manipulating tools

One of the core challenges in designing and deploying project-based curriculum is keeping a focus on the scientific concepts and models motivating the activity. Efforts to use science activities to reinforce specific curricular concepts can tend towards pre-formulated activities which leads learners through a "cookbook" set of instructions [34]. On the other hand, open-ended activities based on student inquiry can at times wind up being only tenuously connected to the scientific concepts they are meant to engage. [20] In both cases, students and instructors can become preoccupied with the materials and procedures of laboratory work—either because they are caught up in following the recipe instructions, or because they are focused on open-ended design issues—to the detriment of meaningful, conceptual-driven inquiry and discovery.

Data aggregation and visualization technologies may be instrumental in keeping the focus of laboratory activities on the broader scientific principles motivating them. Efficient use of technology to collect and analyze data can save time and allows for examination of larger data sets, leaving more time for discussion and reflection on what students were observing. Common measures can be encouraged and visualized across student-driven projects, conceptually unifying diverse arrays of activities. Learning can be assessed by direct queries about their analysis of data produced by their projects over different trials or design iterations, giving more relevant information about their understanding of specific concepts than more typical assessments measuring how well they followed the procedures for the labs or how impressive their projects look on display.

Supporting Social Interaction

Data-driven laboratory activities can illuminate key relationships between natural phenomena and facilitate the process of discussion and analysis that is a critical aspect of the scientific process. Collaboration is a key component of most project or lab based science classrooms. Arrangements in which students work together to inquire, solve problems or design solutions seems particularly effective because they engage students in social talk around science. [24] [32] Data helps enable this process, giving students something concrete and visible to talk about, construct arguments around and come to agreement over, all key components of science itself. [27] For example, researchers on the CoVis project demonstrated the use of *collaborative visualization* to ground social discussion and analysis of observed phenomenal and systems [32]. Mobile, handheld digital data collection devices open up possibilities for new collaborative arrangements in classrooms. Data within more loosely structured "open ended" projects can anchor interactions around core curricular concepts, be those interactions informal conversations with teachers or lab partners or more formal assessments of learning.

The issues of cost and size of equipment are an important to schools in general and to enabling social interaction in particular. Because the per-unit price and storage size of laboratory equipment can dictate the group set-up in a classroom, having equipment be inexpensive and portable makes it easier to have students work in small groups of two to five, considered a cornerstone of cooperative learning [9].

Harnessing everyday and embodied understanding

The importance of grounding understandings in first-hand experience is one of the tenets of constructivist pedagogical approaches. Research shows that in the realm of physics, however, students' naïve interpretation of everyday events can lead to critical misunderstandings of physical principles. Students' everyday experiences, as well as images in movies, cartoons and videogames, may contribute to their misconceptions; discussing at a conceptual level may not correct student's incorrect beliefs, as learners tend to selectively understand or distort information in order to maintain their conceptions. [4] By framing videogame related experiences within the context of a class, and with the presence of measured data, we can provide anchoring experiences [2][4] that would help surface students misconceived intuitions and make them visible for discussion.

Enabling more data, in more classrooms, more often

While biology and chemistry labs have long used sensors to provide students access to real data regarding water quality or chemical compositions in the course of labs and projects, physics classes often have relied on analog manual data collection devices (for example, stop watches), if any data is used at all. This makes it difficult to aggregate data across timescales and classrooms. In addition, specialty 'demonstration' technologies such as constant velocity cars, are often expensive, non-interactive, and limited in capability. The dearth of affordable tools to examine complex concepts related to energy and motion, such as forces, velocity and acceleration, is particularly unfortunate because misconceptions in these areas seem to be particularly robust [23][42].

PROJECT OVERVIEW

The Wii Science project is a multi-year collaborative project funded by the Wallenberg Foundation. The purpose of the project is twofold: 1) to develop activities and software tools that encourage young people in and out of school to repurpose everyday technologies for their own interests and pursuits; and 2) to design activities and software to support scientific inquiry in science classroom labs and projects. Researchers from the engineering and education schools of Stanford University are working in conjunction with a 6th grade physics instructor, Pote Pothongsunan, from Nueva School in Hillsborough, CA, to define the goals and activities. During the first two years we have observed and worked with six classes of students as they conducted hands-on physics projects and lab activities in their science class.

We have used a cooperative design approach on this project, basing our initial design prototypes on observed activity and needs, and framing the instructor and students as co-designers in this engagement. Most of the laboratory and project activities described in this paper build upon longstanding activities at the school, designed with a constructivist pedagogical approach in mind and honed over many years of practice by different teachers. After observing and analyzing the dynamics of these activities during the first year, we worked with the teacher to select activities for which data collection using Wii Remote's accelerometer and IR camera held promise to enhance student engagement and learning.

Methods

We structured our engagement with Nueva school as a cooperative design activity with two distinct phases. In the first phase, we primarily focused on sustained observation of classroom and lab activity in order to understand the design context. In the second phase, we introduced design prototypes to instrument lab activities in the classroom, solicited feedback and design refinements while also observing impact on classroom dynamics and learning. We framed our relationship with the instructors and the students as co-designers of the tools and curriculum. This cooperative design approach is reminiscent of participatory and collaborative approaches outlined by Inkpen [14], Druin, [8] and others working in the realm of classroom technology research and design [34][17].

Participants

All of the participants were students taking a 6th grade physics course with Pote Pothongsunan, our partner instructor at the Nueva School in Hillsborough, CA. Nueva is a private K-8 school with selective admission and a reputation for its special emphasis on constructivist pedagogy and social and emotional learning. Sixth, 7th and 8th grade students use school-issued laptops for their coursework. While we considered several schools as potential partners for this project, Nueva School was selected because the school was able to commit to a multi-year project, because it provided had the needed flexibility in their curriculum to accommodate our design experiments as part of the normal class structure, and because the pre-existing base of common computer hardware would allow us to focus on one version of each design prototype rather than several for each operating system.

OBSERVATION PHASE

During the first phase of the project, we focused on observing the instructor and students in the classroom, understanding the current structure of the course, surveying students about their technology usage and their understandings about their lab activities.

To profile the degree of technological familiarity in the participant population, we constructed a survey that integrated a Learning Ecologies protocol [1] and the Computer Attitude Questionnaire [19]. The results of this survey (see Table 1.) confirmed that most of the students had a high degree of access with and familiarity to both computer and video game technologies. The tech attitude score were calculated by summing the CAQ responses registered on a 5-point Likert scale. The CAQ questionnaire asked questions about attitudes towards technology, allowing students to select along scales that, for example, ranged from enjoying using technology, being comfortable with technology, to avoidance of technology and technology frustration. Both boys and girls scored high in positive attitudes on the questionnaire, with boys slightly more positive about technology than girls.

Table 1. Technology ownership & use in participant population

Devices	Have used	Have in Household	Personally Own
Cell Phone	84%	94%	64%
MP3 Player	94%	94%	90%
Laptop	96%	98%	96%
Desktop	63%	94%	47%
Game Console	84%	62%	46%
Wii	86%	70%	50%
Gaming Handhelds	83%	69%	63%

After conducting a brief Wii Remote orientation activity with students to check their technical understanding and experience with graphing (described in detail below), we then attended classes and labs weekly, documenting visits via field notes, photos and occasionally video. Among the projects we observed were a traditional 'spark timer' lab for students to explore acceleration; a mousetrap car project, in which students worked in pairs to design vehicles powered by a mousetrap's spring mechanism; an 'egg drop' design project in which students worked in pairs to design a contraption to protect an egg as it was dropped from a 40-foot breezeway; and a marble rollercoaster, in which students were given foam tubes, glue, tape, cardboard, cups and wood to build a rollercoaster to meet specific constraints.

We used these observations to inform the design of activities to introduce a data collection into the curriculum.

DESIGN PROTOTYPE PHASE

During the following school year we introduced software prototypes designed to facilitate using Wii Remotes within lab activities. We regularly visited our partner teacher's three physics classes, dropping in weekly during regular class periods, and near daily during lab and project activity sessions. During this phase we more actively sought to identify student's physics misconceptions and opportunities for remediation. We worked with the instructor to introduce our prototypes into the activities, and during the projects and labs worked with students, often making improvements on our designs during the activity itself. We documented our interactions in the classroom through video, pictures, and field notes.

Participants

Fifty-six (30 girls and 26 boys), 6th graders from three physics class (with 20, 20 and 16 students each) at Nueva School taught by our partner instructor. The age range was from 10-12 years old.

Wii Remote Orientation Activity

As in year one, we conducted a classroom activity that helped to introduce ourselves, the project and the Wii system. We used this activity to assess prior understanding of its components and functioning, and to check students' experience with graphs as well as their stance towards viewing the device as a general purpose tool.

Divided into groups of four, students alternately played and observed Nintendo's Wii Tennis game to analyze how the games worked. We asked the class guiding questions to help students make connection between the output generated by the device and the devices components, and asked them to imagine its possible uses beyond gaming. We then showed them real-time data outputted from the Wii and visualized using software we had written in the Processing language. While the previous year we had used Darwin Remote to visualize data, this time we demonstrated the accelerometer sensor data from the Wii using our own software program so that the students could see the code responsible for processing and displaying the data. This was part of an effort to emphasize that the interfaces they would be seeing would be in development, and subject to feedback and corrections.

Students successfully deciphered the many input-output relationships in the Nintendo Wii System, and were able with prompting to deduce many of its components. Despite this, they still had many naïve notions of how it worked. For example, some students thought that some Wii Remotes were more powerful than others based on their color. Although many had mastery over technical terminology, speaking of infrared (IR), Bluetooth, and accelerometers with ease, understanding was shallow. For example, many students knew that the Wii Remote "had Bluetooth," but they did not understand that Bluetooth enabled the device to send sensor data back to the gaming console.

Students had difficulty interpreting the acceleration data, which was visualized on a moving line graph. Their explanations about causal relationships in the graph were centered around position and velocity rather than acceleration. The three axis were confusing, as was the constant 1g measure of gravity. As in the prior year, although they could describe components, students had difficulty generating ideas about other uses for the technology.

As a second part to the original orientation activity, we held a session where we led students through the installation of the Processing application, some introductory interface prototypes, and the pairing of Wii Remotes to their computer. The goal was for each student to have the prototype software on their machines so that they could use it, inspect it or modify it, and would know how to sync the Wii Remote to their laptops. We also issued a survey to assess their current understanding of basic physics principles, and to ferret out some of their misconceptions to consider how these might implicate design.

Mousetrap car

In the mousetrap car activity, students were challenged to build a car based on a mousetrap. The activity itself spanned 8 hours of class time, and took place just after students were introduced to basic concepts of forces. We were able to informally interview the teams about their strategies and design challenges they were encountering. While many correctly identified weight and friction as key issues in the design of their cars, they also echoed common misconceptions that we found earlier in the year.

For example, when trying to decide what material to make the body out of, one student chose a heavy wide board. When asked about why, the student noted that "forces make you go" and that "more weight" would "help it stick to the ground more. So if it sticks to the ground more, it has to move faster." Another student described a similar decision, drawing on his everyday observation that "heavier cars go faster." In their tinkering, few students considered that the only variable they could not control easily was the power of the spring. After discovering that their heavier cars did not move very fast or far, they explained that the "string doesn't unwind fast enough with this weight. Because of friction."

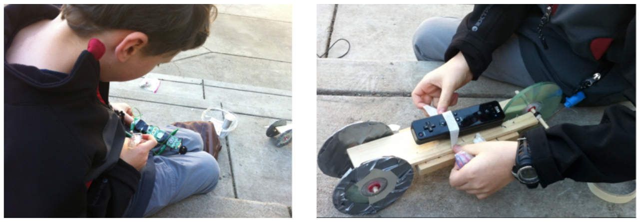

Figure 1. Photos of the stripped down Wii and the WiiMote on a mousetrap car.

Once cars were designed and basically functional, we assisted students in attaching the Wii Remotes so that their car's acceleration could be wirelessly sent to a laptop display. (We intended to introduce the measurement earlier in the design process, but in part because were piloting new tools for the first time, the instructor requested the measurement activity as a separate phase of the students' projects.) As the first team attached the Wii Remote to the top of the mousetrap car, several issues immediately arose. The remote got in the way of the lever arm, and added significant weight to the car, slowing it to a crawl. The graph was barely visible on the vertical scale we had chosen, and the "noise" generated by the Wii Remote's loose masking tape attachment and the bumpy pavement dwarfed the acceleration readings we were after. Several teams became interested in the problem, discovering that they could mount the Wii Remote on the bottom of the car and use more secure mounting methods to get better data. One student in particular became intrigued with taking the Wii Remote apart and powering it with a lighter battery. While this solved much of the weight issues, it raised other issues, such as short battery life. Another team shifted to a rat trap rather than a mousetrap to better host the size and weight of the Wii Remote.

We made numerous changes to the prototype interface and the activity design during this trial, including adding the ability to stop and start the graphing function as well as the ability to more easily save image files. In addition, we made it easier to turn off and on the view of each different axis so that attention could be focused on one axis at a time. One instance when this feature proved critical was during the heated in-class debates about negative acceleration; the acceleration line dipping below zero stirred the most discussion amongst students, with some students expressing understanding, while others lacked accurate explanations. One team was convinced that fact that our graphs showed negative acceleration in this context indicated that our sensing system "wasn't working" and ran several trials to bear out their hypothesis.

Power Punch

In response to some of the misconceptions and design issues uncovered in the mousetrap car activity, we created a new lab activity to enable students to use the Wii Remote to study acceleration more explicitly. Because it was not tied to a larger ongoing project, this lab enabled us to focus the whole lab on measurement data.

The Power Punch lab took place during a single class period, several weeks after the mousetrap car activity. Students were asked to consider what the acceleration graph of a punch would look like. The instructor demonstrated by holding her right hand at her side and thrusting it forward as if hitting a punching bag. The arm was not withdrawn. The example was repeated several times, and the students were asked to draw what they would expect to see on an acceleration graph. These were collected.

Students then were asked to use a Wii Remote to see if they were right. They followed instructions to tape strings to their Wii Remotes, and hang them vertically in a tube; this allowed the effect of gravity to be zeroed out, and for all of the punch's acceleration to be captured on a single axis, simplifying the data. As a student gripped the string and punched, the Wii Remote was vertically displaced within the tube. The interface showed both a bar graph that indicated the acceleration at the current time, and a line graph illustrating the acceleration over time. Students worked in groups of three or four to capture their punches. Each team paired a Wii Remote to one student's laptop, and began conducting trials. Students were given handheld cameras and were asked to video their predictions and their trials.

While one class ran out of time due to pairing issues, the other two classes gathered together after each team had conducted several trials. Students were asked to come to the board and draw their acceleration graphs. When enough were on the board, the instructor asked what could be generalized from these. Students agreed on the general shape of a punch graph, and then as a class began to debate how to map the graph to the actions.

The graph showed a sharp rise, and then a smaller sharp dip below zero, and then a recovery to the zero line. Again students struggled with negative acceleration, sparking engaging conversations. In one class some students claimed that the reversal to the negative must have been when the punch was withdrawn to the punchers side. Others refuted this, because this did not match the action of the assignment or that recorded on the video. In response another student piped up and said "no, it's the up and down of the Wii Remote" indicating the rising and falling of the Wii Remote within the tube. As her hand was moving up and down she hesitated and said, "wait… wait… I almost got it!" Another student exclaimed "wait – we did this! Its moving.. no… Its not.. its.. slowing down!" Because of the shared discussion of the data, we were able to witness firsthand the student's struggles coming to grasp the concepts in question.

Despite that students had studied and graphed acceleration in the months prior and had "done" negative acceleration following their mousetrap car experience, their intuitions related to positional displacement in the direction of motion were the most available to them when considering the graphs. While graphical representations of change in distance over time are difficult to grasp, considering change in change is much more complex. While they "knew" the formulaic answers of how distance, velocity and acceleration were related, the motion of their own arms' displacement was much more readily available than considering change in speed. Like in the mousetrap car project, only a few of the students in all three classes predicted a pattern that included negative values before the activity. However, unlike the graphs of the mousetrap car, no students indicated intuitive understanding of the graphs of their punches' acceleration.

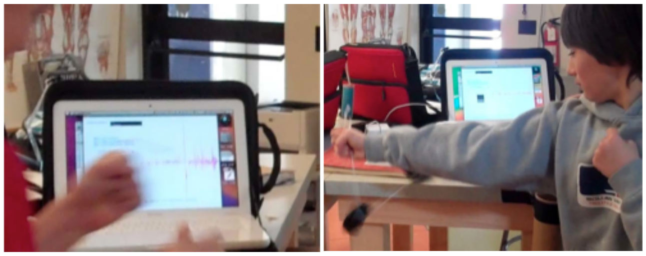

Figure 2. Photos of students engaging in the power punch activity

Roller coaster

The third project with which we engaged was the marble rollercoaster project. The instructor suggested that this design prototype measure velocity rather than acceleration because the activity was tied to a unit on energy formulas that use velocity calculations.

To measure velocity, we decided to use the Wii Remote's IR camera. At first we planned to embed infrared LED lights inside balls for the camera to track. However, it became difficult to balance the batteries inside the balls so that it would roll properly. We then switched to a different strategy – to paint the marbles with retro-reflective paint so that IR lights, mounted on a ring in around the Wii Remote's IR camera, would capture the moment the ball passed. However, it was difficult to get the paint and glass beads to stay on the marble, and, although it worked well in a test environment, when we got into the classroom we picked up lots of interference from the school's security cameras. In the end, we switched to a "photo gate" strategy, placing IR LEDs on clips that students could mount along the track. When the ball passed, it interrupted the camera for a period of time, providing entry and exit points that could be used to calculate the velocity of the ball.

Because one of our goals was getting students to see the Wii Remote as a flexible tool, we spent some time explaining to them the different strategies and what we finally settled on. We presented a very brief Powerpoint on IR light and how the camera works, then showed them how to view IR lights via a cell phone camera and discussed the various strategies we had considered. Then students set about setting up IR lights and Wii Remotes.

During this activity, we noticed that some of the displays the student teams were using differed from those that we had originally designed; when questioned about why the colors and sizes of features in the interface were different, students showed us the places that they had changed our code to improve the interface.

OBSERVATIONS AND FINDINGS

The engagements with our participants allowed us to test and refine our ideas of how handheld gaming technology might foster new and effective practices in laboratory and project-based learning. We review each in sequence:

Manipulating ideas via manipulating tools

Based on a review of the literature that described "cookbook" science [34] in which students followed directions and manipulated equipment according to instructions, one of our own design challenges was to create a system whereby more time was spent on manipulating ideas than manipulating equipment. On the whole, students did spent lots of time manipulating equipment. However, unlike "cookbook" science, these moments often intersected with manipulating ideas. Rudimentary tasks such as pairing Bluetooth or positioning the remote to zero out gravity engaged them in thinking about how the Wii Remote worked as a tool, and led to conversations about syncing and calibration which are fundamental to experimental science. In addition, the presence of real-time data helped students consider why it is necessary to be fussy about the technical mechanics of lab work—for example, proper taping of the sensor leads to less noisy data. The process of collecting scientific data with scientific tools moved to the foreground.

However, the time spent manipulating equipment took away from opportunities to engage students in dynamic discussions of their data and for students to use that data in redesign. In particular, we faced technical issues with pairing of 20 Bluetooth devices with 20 laptops in one room. While we developed work-around procedures to make the system work, the nitpickiness and likelihood of failure would keep these tools from working in a broader set of classrooms without substantial improvement.

The equipment also seemed to have some valence of its own, generating a change in activity in terms of energy and interest. The Wii Remotes newly positioned as tools were intriguing, and the idea of "hacking" a toy into a tool was new and "cool." Students were excited and enthusiastic about using them in their projects; they spent significant time engaging in teamwork to solve problems related to the Wii Remote's use. While we did not intend to have students spend so much time troubleshooting the technical underpinnings of the technology, the repositioning of the students' relationship to the technology fulfilled one of our key project goals.

While capturing and visualizing data was exciting, analyzing its meaning was hard work. Not surprisingly, when students were left to their own devices, they attended more to design aspects of their projects and to collecting data with the Wii Remotes than to analyzing the data they produced. We observed that this was in part related to the structure given to the assignment. While it was exciting to "add" data to previously designed activities, in the future we would like to structure the activities themselves around the data. For example, students could be the more specific, data-driven challenge to build a mousetrap car that reaches a specified acceleration and stops within a given distance, rather than to build a mousetrap car and observe its acceleration pattern. With this change in activity structure, engaging with data becomes part of the fun of the design activity itself. We think the most successful activities will integrate data analysis learning moments into the hubbub of the design and lab activity. If carefully designed, we think this could be done without substantially lengthening the overall activity duration.

Supporting Social Interaction

The Wii Remote's mix of familiarity and complexity seemed to work in favor of student social interaction around both the device and the physics underlying it. Consider the following:

Two students are trying to attach an IR light to the side of their roller coaster so that they can get a measure of velocity as the ball passes the point. One student has positioned the light on the same side of the track as the Wii remote, so that the IR camera cannot see the IR light. Another student is helping but staying quiet. A third is watching in frustration.

B. "No, [it goes] here."

A. "No ... It has to bounce… hold it still"

B. "It can't SEE it." "Move."

A. "Yeah but hold it still, it will [bounce]."

B. "Light doesn't bounce."

A. "Yes it does its IR you cant see it cause its red"

B. "But the sensor has to see it when you swing it." (He makes a move as if playing Wii tennis just before grabbing the IR light clip).

A. "Stop! It can't go like that it will block it!"

B. "But it has to block it!"

A. "It needs to see when it goes by so it can bounce"

The first student has confused two models of tracking IR light – one using retro-reflective paint so that the light will "bounce" off the ball into the camera, and the other using a "photogate" system, so that a steady light is blocked by the ball to trigger a timer. This led to a rich discussion about the nature of light 'bouncing,' waves, how a camera works, the light spectrum, and the misnomer of the 'sensor' bar in the Wii system. It further led to a conversation of binary switches, measurement of time, and instantaneous versus average velocity. The negotiation over tinkering with the tool to measure physical phenomena led to a rich debate and eventually a deeper understanding of related concepts.

Students worked in teams on all projects, and in this vein socially engaging in "science talk" in ways that have been shown to be productive for learning. [24] [32] We followed several teams closely and have noted frequent discussion and argumentation over all aspects of activity. In addition, there was significant cross team fertilization of ideas, as students were free to wander about the space and observe what each other were doing. While we originally planed for each student on a team to have a Wii Remote paired to their own laptop, we were glad that we shifted to a one-laptop-per-team solution. The shared screen facilitated joint attention to data and group conversation – which made considering data more fun and more meaningful.

In addition, students frequently discussed playing various Wii games at home, acted out mock gaming play, and made inside "Wii" jokes while playing with the equipment. We theorize that the Wii Remotes in this case were traversing the different worlds of home and school, serving as "boundary objects" [10] that connected their peer-oriented, home-based play worlds with their new activities in physics class. Several students asked if they could download the software later and use it at home with their own Wii console. Just the possibility that the software tools could be used in the future among friends seemed to add importance to the lab activities, inviting participants to project themselves into a world in which not only did play enter into physics, but physics entered into play.

Harnessing everyday and embodied understanding

Our findings around everyday and embodied intuitions are contradictory. Students have an intuitive sense of the use of the Wii Remote technology due to their experiences in game play. We assumed that these embodied experiences would correctly inform students' intuitions about abstractions related to mathematics and physics [15]. Our observations suggest, however, that for concepts such as velocity and acceleration, the experiences of motion in the body may be misleading. For example, when examining graphs of a the change in a car's velocity over time, most students were readily able to explain negative values as the car's "slowing down." This was despite that their initial predictions of the graph showed no negative values. However, later, when examining the graph of a punch, experienced firsthand, students had difficulty conceptualizing negative values, sometime "remembering" their experience of distance displacement to fit their observation of the graph. For example, in the vignette below, two students are working with the "punch" set up together on a laptop. The instructor passes by :

C. "No she said don't pull [your hand] back!."

D. "I didn't… stop [the graph]"

C. "Yes – look " (Swinging his arm in a play punch to lab partner while pointing to the line sharply dipping below zero on the screen).

D. "Ow. Oh.. but… it [the line graph] kept going. Let me.." (Students set up and same student replicates the punch, this time with arm held out, visibly still)

C. "It went again… it bounced in the tube."

D. "No but…. Ok. it's speed… so it stopped. NO! Its acceleration. But… the speed stopped. But (looking back at the tube)… It fell back… "

C. "(Audible groan). No it didn't…it stopped. Yeah… but… It's here see" (pointing to negative values and then yanking the string up and down).

Instructor. (Overhearing while walking by): "So. Wait. Why is the graph below zero?"

C. "Yeah. Cause it got messed up. He pulled his hand back. Do it again…"

It seems that that watching a car start and stop under its own propulsion outside ones own body gives a clearer overview of forces involved than does the experience of watching a graph of a self generated punch. While students feel themselves generating the punch, they do not feel themselves "stopping" it, as the punch is limited not by muscle action but by the limits of the length of the arm. In this case, students must decouple their intuitive phenomenological understanding of how it feels to punch from the abstraction of "acceleration." We think this hypothesis would be interesting to follow up on in future studies.

Enabling more data, in more classrooms, more often

Although in this early design phase we have yet to implement automated data aggregation and visualization across teams, students were able to generate and visualize more data, in more class periods, more frequently than in the prior year. Already we could see how these led to loud but useful debates (for example, about negative acceleration). By generating data related to the same concepts across several different projects throughout the school year, students encountered more representations of difficult concepts in physics (such as acceleration) in shorter time spans across disparate contexts. Studies indicate viewing multiple representations across various cases is beneficial for conceptual transfer of learning; however, we lack controlled assessment data to prove that students learned more than in prior years.

DISCUSSION

Thus far, we generally confirm our hypothesis that handheld gaming remotes offer specific properties that make them uniquely situated to be useful for science classrooms. Among these properties are the linkages between the devices components and complex concepts in physics, the familiar and social nature of the devices in children's everyday lives, and its capabilities to rapidly, frequently collect, and with software, analyze and visualize large quantities of data for discussion. However, our hypothesis that embodied experiences of game play contribute to conceptual understanding of physics did not play out as we expected. While we conclude that the everyday playful nature of the device makes it accessible and interesting to children, whether or not children's 'embodied' felt experiences of acceleration in game play contribute to or interfere with understanding of acceleration is a matter for further study.

Overall we found that embedding data in student projects provided anchors for integration of diverse design projects within the curriculum, and that when offered the opportunity and some guidance, students will tinker towards abstract concepts in physics as they tinker with familiar tools of its measurement. We recognize that in the case of this project however, the researchers had great influence over students tinkering. It is likely that to a significant degree students' engaged stance towards the inner workings of the technology was enhanced by their collaboration in a technical design research project run by adults engaged in tinkering. As this is relevant to our conclusions, below we further describe this cooperative 'tinkering' stance in our design process, and follow with some conclusions of design opportunities for using handheld game controllers in classroom settings.

Cooperative Design Process

The cooperative design process contributed significantly to both the software outcomes and, we think, student learning. Because we spent significant time in the classroom before any intervention, we, the students, and the staff were familiar with each other and the project. All participants were positioned as part of the design process, each with different roles. Particularly interesting was the students' perceptions of their role in educating researchers. Students were critically engaged in the activities in which they were participating, using the tools but also considering whether activities they were doing were effective for learning. Students felt free to give us feedback on both process and product, as well as to orient us to their expectations in terms of classroom culture. For example, after receiving a list of instructions on how to pair the Wii Remotes, two girls approached and gently told us that at this school "we explore, we don't follow instructions."

Students also gave excellent feedback on the software, pointing out interface issues and aspects that made concepts difficult to understand. Their position as co-designers of the software also seemed to alter their positioning towards the Wii technology itself. Because initial designs were prototyped in an open programming environment, student could read the code before running it, and could make changes and alterations. Several times teams changed sections of code to make things easier to see. Several students spent time watching how data was being read and asked questions about programming.

Students critique was not limited to software and activities, but also extended to the researchers' pedagogical approach. After one particularly complex presentation about infrared light, students had a hard time putting all the pieces together and were frustrated. After some more discussion after class, the teacher assigned them to team up to create a better presentation, so that the researchers could learn how to do it "more kid friendly" next time. Students enthusiastically created detailed Powerpoint presentations, hand drawn comics, animations, movies of action in 3D worlds, and Scratch [33] animations that showed how a Wii IR camera worked and how one could use it to create a photo gate system. Each team presented to researchers a week later, affording another opportunity for us to interview them about the project, and affording both researchers and students the opportunity to "teach to learn" and "learn to teach." Each presentation used vocabulary and analogies that the youth said other kids could relate to. Most students agreed to our request to eventually host these on our web site so that other students could learn from them when the software is released.

While the collaboration was informative for both design and learning, we also ran into familiar "gotchas" in the collaboration process. Institutional time frames that don't match up make workflow difficult. The school is for academically talented students for whom appearing knowledgeable is generally important, and we found it took encouragement to get them to reveal that they might not understand things. In some cases ,it appeared they wanted to please us or the teacher, and so had difficulty expressing mistakes or partially formed ideas rather than an "official" correct answer. As is probably typical, we found that while we were tinkering towards technology and physics, we also were slowly tinkering towards an effective culture of collaboration.

Design opportunities

Several design opportunities present themselves from these findings. First, streamlining the software deployment and computer pairing issues is crucial. Until a teacher can easily pair a classroom of Wii Remotes to a classroom of computers, it will be hard to integrate these activities into school curricula. Along similar lines, it will be very beneficial to social interaction and data-centered reflection to automate the saving and labeling of data output, as as facilitate quick and easy aggregation of the data. Ideally, we would like the teacher to be able to easily bring up anyone's data file to talk about, as well as superimpose results or aggregate results from the whole class on one screen. In addition, we frequently asked students to videotape their trials as they were collecting data. We found this helpful to avoid the "remembering" problem. We would like to integrate video into our tools so that the action and the data could be reviewed side-by-side.

By addressing some of these usability issues, we hope in the next iteration to integrate data measurement into lab and project activities from the outset. This can engage students in considering data in their designs, and make the data more exciting because it would have real impact on design decisions. The same is true with presenting ideas and surfacing misconceptions. Having students present their designs mid-way through would facilitate surfacing misconceptions early on, so that they could more explicitly examine their naïve ideas in light of data that contradicts them. Benchmark break points in projects would provide opportunities for intervention along both these lines.

CONCLUSIONS

We expect this design research, as well as other studies in this vein, will contribute not only to the design and integration of technology into classroom science inquiry practices, but also add fodder to discourse of what makes constructivist "hands-on" learning effective. Recent work has begun to challenge the polarization between creative student-driven "open-ended" exploration and curriculum driven direct instruction. [36] We propose that everyday, low-cost mobile sensor technologies such as game controllers can engage students in student-and-curriculum driven practices that are effective for learning. By engaging kids in manipulating ideas via manipulating tools, by supporting social interaction, harnessing everyday and embodied understanding, and enabling more data, in more classrooms, more often, these tools can promote greater synthesis of the interests of children and the interests of the curriculum [6].

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