2017 HAWAII UNIVERSITY INTERNATIONAL CONFERENCES
SCIENCE, TECHNOLOGY & ENGINEERING, ARTS, MATHEMATICS & EDUCATION JUNE 8 - 10, 2017
HAWAII PRINCE HOTEL WAIKIKI, HONOLULU, HAWAII

TT'S ALL FUN AND GAMES UNTIL SOMEBODY LEARNS

RUECKERT, FRANZ ET AL
SCIENCES AND INDUSTRIAL DESIGN DEPARTMENT
WENTWORTH INSTITUTE OF TECHNOLOGY
MASSACHUSETTS

Dr. Franz Rueckert
Dr. James O'Brien
Dr. Gergely Sirokman
Prof. Derek Cascio
Sciences and Industrial Design Department
Wentworth Institute of Technology
Massachusetts.

It’s All Fun and Games Until Someone Learns

Synopsis: At Wentworth Institute of Technology the authors led students of both Industrial Design and Physics in the creation of gamified lab kits that deliver a more complete learning experience for all participants. In this paper, we review the process and creation of the lab-kits from both scientific and design perspectives. We then show how the design and implementation of these lab-kits led to appreciable gains in both physics and design learning environments.

Abstract

Though not at first evident, the seemingly disparate fields of Industrial Design and Sciences share significant overlap in their approach to learning. The classic scientific method of hypothesis, experimentation, and analysis is remarkably similar to the design approach of ideation, prototype, and refinement. This presents a unique opportunity for interdisciplinary collaboration on the pedagogical methodologies that bridge the two disciplines. Using the principles of gaming as an educational platform, the authors created two new gamified lab-kits, *Sector Vector* and *Resistile*, to replace traditional introductory physics laboratory activities. Herein, the authors review lessons learned in the development and implementation of each lab-kit.

At the heart of any STEM program is a solid foundation in the basic principles of physics. However, typical laboratory exercises associated with these crucial lessons are often purely technical and generally uninspiring. As a key concept of Industrial Design (ID) is product design, a collaboration between ID and Science faculty was the perfect partnership to refine these educational tools. A rough prototype of a board game which could convey scientific principles was initially developed by the authors. ID students were then tasked with refining and perfecting the game. The goal was to produce an interactive and fun laboratory experience that preserved, or better yet, improved the lesson. Meanwhile, physics students were engaged in the project at two levels. They served not only as recipients of the lesson itself, but also provided important feedback to aid the ID students through the multiple stages of the creation and refinement process. In this way, the curricula of each discipline enhanced the learning experience of the other. Physics students were immersed in creative arts and design while ID students tackled mathematical formalisms. This interplay between science, design, art, and mathematics is the epitome of a STEAM learning model.

In this talk, we will describe the advantages and benefits of this cooperative approach. We will also outline the advantages of setting fun as a distinct learning goal. Soft skills such as peer learning and engagement are more easily achieved through the exciting competitive atmosphere created by a game. Moreover, the lasting positive impression of this type of experience increases retention of key concepts.

It’s All Fun and Games Until Someone Learns

How do you make the science classroom more engaging? This is a perpetual question for educators. In recent years, the idea of active physics [1-3], SCALE up physics[4] and flipped classrooms [5] have shown positive results. Additionally, recent literature has shown an increased interest in using gaming as a teaching tool [6]. “Gamification” in education is typically a renormalization of class assessments to typical gaming progression indicators (such as changing from high grades to high scores). Being active gamers as well as educators, we see an advantage in the goals, cooperation, competition, and objectives typically found in complex immersive gaming but we have taken a different approach. Rather than restyling the classroom environment, we sought to replace standard learning experiences with gamified alternatives.Through a partnership between Science and Industrial Design we have a created unique alternatives to standard science classroom modules via the introduction of physical gamified lab kits.

In this paper we will begin by outlining the design and development process for two projects which exemplify the Externally-Collaborative, Interdisciplinary, Project-based Culture (EPIC) for learning at Wentworth Institute of Technology (WIT). We will then review the implementation of the lab kits themselves ending with a discussion of the pedagogical impacts of both the soft and hard measured learning outcomes from each kit.

An EPIC Quest

Having run introductory physics labs for many years, the science faculty authors identified key areas where passive and frankly boring laboratory exercises could be replaced by this new gaming pedagogy. The science authors developed a rudimentary prototype for a new gamified lab kit which was tested with positive results (Figure 1).

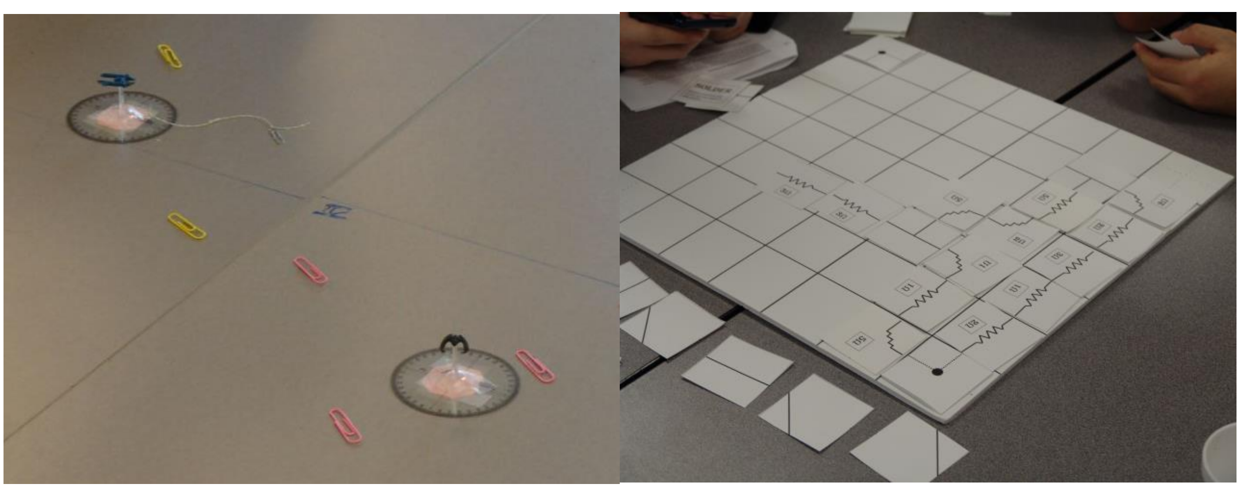

Figure 1. Early Sector Vector and Resistile prototypes developed by Science Faculty

This was encouraging but it was clear that additional help would be needed to take it to the next level. The next step was to reach out to the Industrial Design (ID) faculty and discuss a collaboration. Industrial Design is by nature a hands-on, experiential discipline aimed at producing products making them the ideal partner. The ID faculty saw immediate potential in the concept and recognized its educational value for their students as well. Thus the lab kits would serve double duty-as a teaching tool; practicing class concepts for the Physics students and providing a real world challenge to the Industrial Design students. This partnership would lead to the creation of two game based lab kits called *Sector Vector* and *Resistile*.

From initial concept to final prototype, the creation process took approximately six months. Each kit served as the final deliverable for a semester long course. In the Spring of 2014 and 2015, a Senior level Industrial Design studio course was created entitled “Game Design: Creativity and Play to Enhance Education,” with an enrollment of 11-12 students. The semester goal for these students was to successfully create a refined product which would deliver the learning objectives of the lab in an entertaining manner.

The first kit, *Sector Vector*, was to be designed was a new, engaging way of teaching vector algebra and decomposition.These challenging concepts are arguably the most important concept in the introductory physics cycle. Although attempts have been made at making a more active lab exercise for basic vector manipulation [7], many focus on repetitive drilling similar to homework assignments are already found in the course, such as navigating a map and or using force tables. Our second kit, entitled *Resistile*, provides students with an interactive and evolving circuit highlighting basic circuit elements and the mathematical properties of their respective manipulation. Typically this type of lab is covered by connecting simple resistors (i.e. lightbulbs) in series, parallel, and various combinations, typical of an array of homework problems.

It is well known that repetition is the key to developing the problem solving skills required. The original standard labs, however, do not engender a desire to practice. Rather, students typically attempt to finish the assignment and leave lab as soon as possible. It is here that gamification is most beneficial. By making the experience fun, students are encouraged to keep playing, and thus keep learning. A successful game invites players to return again and again to improve their performance. Using the game as a dynamic lesson, this replayability is now a chance to practice problem solving skills. A successful lab kit is one with the replayability of a great game and the learning objectives of an in depth problem set.

These kits bring with them unique constraints like any design problem and cover material unfamiliar to the ID students. Tackling these topics requires first hand research and analysis. To that end the ID students observed Physics students playing versions of the labs and gathered data through interviews and questionnaires (Figure 2).

Figure 2. Design students observe and record gameplay of early lab kit prototypes

While this type of research is imperative to the success of any design project observation alone is not enough to fully understand a problem. As such, ID students performed the labs first hand stepping far outside their comfort zone learning how to calculate vectors and resistance across a circuit. From all of these activities the students gleaned numerous insights around gameplay mechanics, physical components, team dynamics and perhaps most importantly, which elements were fun. These provided opportunities that could be leveraged in the next phases of the design process - ideation and prototyping. The students then developed concepts, first in 2D and then though physical 3D models (Figure 3). How the kits will be stored and deployed in a classroom, how many pieces they might include and how easy the rules are to understand were just some of the concerns at front of mind.

Figure 3. Examples of 2D and 3D design development for Sector Vector

It is at this point that Physics students and faculty were invited to come and play test the first prototypes which are permutative in nature. Each concept strives to address the identified design opportunities in different ways while all working to meet the design criteria set forth at the beginning of the project. Again, the physics students are both passively observed and actively engaged with in an effort to identify what works and what does not (see Figure 4).


Figure 4. Physics students test out prototypes for Sector Vector (left) and Resistile (right)

With new knowledge in hand the designers iterated on their concepts and tested again. This process is repeated with refinements occurring each time until a solution is reached (see Figure 5) that serves all of the learning objectives set out by the Physics faculty and is fun enough to keep students coming back for more.

Figure 5. Final prototype lab kits

Experience Gained:

For a complete discussion on the learning outcomes it is important to highlight the various avenues of learning travelled throughout this collaboration. We begin with the outcomes for the physics students who utilize the kits. We will then discuss the gains for ID students.

Vector Math via Sector Vector:

Quantification of this mastery was performed using pre/post testing on the concepts versus a control group which instead used the typical lab exercises mentioned in the development section as well as a questionnaire on preparedness for the material. For the control group, skills in vector manipulation remained relatively constant both before and after the standard map or vector table exercise at a 4% gain. However, students who played *Sector Vector* showed an average of 12% gain. This increase is significant when compared to typical physics education results [8].

Student engagement was measured via time spent on the given lab exercise. For control group, the average completion time was 42 minutes. For *Sector Vector*, the required time of play the game based lab kit was sixty minutes. This number was chosen to keep in line with the average participation time of the control lab. However, on average, students spent 125 minutes playing *Sector Vector*. It should be noted that students opted to play longer than required. Hence, students chose to stay and participate in more than double the time as compared to the control group due to increased interest and engagement.

Sector Vector is played as a cooperative group of four students opposing another cooperative group of four students. This introduces a small level of competition as groups want to "win" the "game." This competition drive students of various levels of competency to work together and promotes peer learning. This is reinforced by the element of role play integral to the design of *Sector Vector*. A clear example of this peer learning was found in the pre/post assignment where a particular student came into the lab feeling "not prepared for vector manipulation" and later became a team leader and won a victory over a team of students who identified as being "well prepared" for the exercise. With these benchmarks in the first implementation, the authors believe the use of such a lab based gaming kit was an initial success and have continued to see positive results utilizing the final product. For a complete analysis of the above results, we direct the reader to [9].

Circuit Analysis via Resistile:
In a similar manner, the authors saw great success with the implementation of *Resistile*. As before, to measure the mastery of the concepts explored in the gamified lab kit, pre/post assignments were given about the material in question as well as an opinion survey about preparedness. A control group was also established with students performing a traditional basic circuits lab. In the pre/post assignment for this grouping questions were rated as simple, average, and involved. Both groups performed similarly in the simple and average questions, but on the involved questions the group who played *Resistile* scored 11% better on the average than those who performed the traditional lab. To measure the engagement of students, time spent on the given exercise was noted. *Resistile* is played in about 20 minutes time. We required students in the *Resistile* group to play a mandatory set of three games which would last about 60 minutes, a time close to the 54 minute average of the time of the experiment for the control group. Similar to our results with *Sector Vector*, we found that students in the *Resistile* group stayed for an average of 118 minutes, once again more than doubling engagement time. Most groups registered an average of 5 games of which three were required, and in one group a spontaneous round robin tournament was initiated. This level of engagement on a lab exercise such as simple circuits is unparalleled. To ensure peer learning the game is played in groups with each group

having multiple goals to accomplish. Having multiple goals of varying difficulty allows for players at different levels of understanding to participate. However, since goals vary in their overall point value for final scoring, groups have to convince one another as to why they should attempt one goal over another. This creates opportunities for peer learning as students debate the best strategy to maximize points. For a complete analysis about the first implementation of *Resistile*, we direct the reader to [10].

Product Design via Gamified Lab Kits

For the Industrial Design students these projects were a treasure trove of learning opportunities. Within design the focus is always on who one is designing for and what problems need solving. In this case the students had an opportunity to learn from and design for their peers which made their investment in a successful outcome that much more substantial. These projects were also an opportunity for the students to explore areas of design that they were not as well versed in but are integral to the ever expanding roles and responsibilities expected of industrial designers in professional landscape. Graphic design, project management, budgeting and documentation are all skills that need to be honed beyond the tradition ID skillset and these projects provided that. The complexity inherent in the design of these kits required every student to go above and beyond testing their abilities to be individual contributors as well as team players. Ultimately, the resulting products and experiences have helped their classmates learn and provided them with well-rounded, in-depth portfolio pieces.

Achievement Unlocked:

As an EPIC collaboration between Sciences and Industrial Design, the benefits of this experience exceeded what either department could have achieved individually. Our multidisciplinary approach also highlighted the similarities between these seemingly disparate fields. The scientific method is one of hypothesis, testing, and observation. This mirrors closely the design approach of ideation, prototype, and refinement. The creative synthesis provided by Design and the technical application of the Sciences creates a synergy which is the hallmark of STEAM education. We note in particular the emergence of a circular learning style, whereby the advances of one group improved the learning of the other; the faculty imparted the students with knowledge, the students then created something used to teach which in turn educated their peers and created new teaching opportunities for the faculty. The best part of all of this? At each phase of this cycle the students and faculty had fun which made the entire learning and teaching experience more impactful, more memorable, and more enjoyable. Lastly, engagement has been shown to be a key element in retention of material [11], and the cyclical learning allowed all stakeholders to “level up” in true academic engagement.

Continue?

Despite the success of these projects the work here is not done... and that’s great. From the moment we started sharing these projects we have been repeatedly asked if these kits are available. We are excited to announce that, thanks to the support of Wentworth Institute of Technology and the continued efforts of the Faculty involved, we are now able to provide this experience to other institutions [12]. It is our goal to continue developing new and exciting learning tools and we hope you can play along.

Credits

The authors would like to thank Sam Montague, Chuck Hotchkiss, and Russ Pinizzotto for their support in this effort. We also wish to acknowledge the efforts of the students of *Game Design: Creativity and Play to Enhance Education* for their invaluable work.

References

[1] David R. Sokoloff, Ronald K. Thornton and Priscilla W. Laws, "RealTime Physics: Active Learning Labs Transforming the Introductory Laboratory," *Eur. J. of Phys.*, **28** (2007), S83-S94

[2] Ronald K. Thornton and David R. Sokoloff, "Assessing Student Learning of Newton's Laws: The *Force and Motion Conceptual Evaluation* and the Evaluation of Active Learning Laboratory and Lecture Curricula," *American Journal of Physics* **66**, 338-352 (1998).

[3] David R. Sokoloff and Ronald K. Thornton, "Using Interactive Lecture Demonstrations to Create an Active Learning Environment, "*The Physics Teacher* **35:** 6, 340 (1997).

[4] Gaffney, J. D. H., Richards, E., Kustusch, M. B., Ding, L., and Beichner, R., "Scaling Up Educational Reform." Journal of College Science Teaching 37 (5), 48-53 (2008).

[5] N. S. Podolefsky and N. D. Finkelstein, "The perceived value of textbooks: Students and instructors may not see eye to eye," Phys. Teach. **44**, 338–342 (2006).

[6] Kapp, Karl M. *The gamification of learning and instruction: game-based methods and strategies for training and education*. John Wiley & Sons, 2012.

[7] See for example, UCONN Physics Olympiad, 2008 Physics Competition.

[8] Randall D. Knight, "Five Easy Lessons: Strategies for Successful Physics Teaching," Ad. Wes (2002).

[9] O'Brien J.G., Sirokman G. and Cascio D, "Teaching Vectors to Engineering Students through an Interactive Vector Based Game", American Association of Engineering Educators, 2014 National Conference Proceedings, (2014).

[10] O'Brien J.G., Sirokman G, Rueckert. F. J.and Cascio D, "Resistance is Futile: A New Collaborative Laboratory Game Based Lab to Teach Basic Circuit Concepts", American Association of Engineering Educators, 2015 National Conference Proceedings, (2015).

[11] R. Hake, "Interactive-engagement vs. traditional methods: a six-thousand student survey of mechanics test data for introductory physics courses," American Journal of Physics **66**, 64–74J (1998).

[12] www.4thlawlabs.com