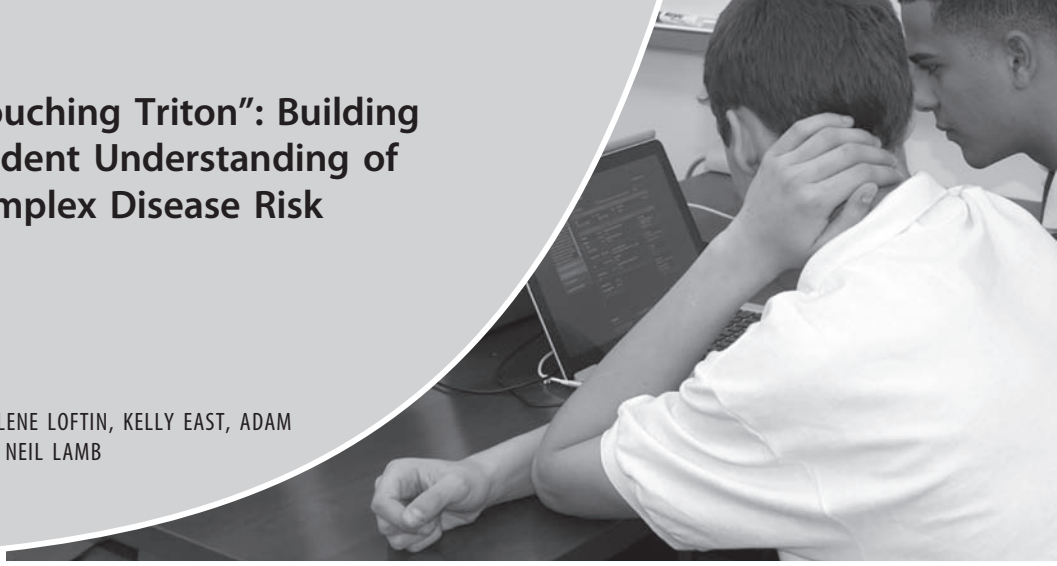
FEATURE ARTICLE

"Touching Triton": Building Student Understanding of Complex Disease Risk



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Abstract

Life science classrooms often emphasize the exception to the rule when it comes to teaching genetics, focusing heavily on rare single-gene and Mendelian traits. By contrast, the vast majority of human traits and diseases are caused by more complicated interactions between genetic and environmental factors. Research indicates that students have a deterministic view of genetics, generalize Mendelian inheritance patterns to all traits, and have unrealistic expectations of genetic technologies. The challenge lies in how to help students analyze complex disease risk with a lack of curriculum materials. Providing open access to both content resources and an engaging storyline can be achieved using a "serious game" model. "Touching Triton" was developed as a serious game in which students are asked to analyze data from a medical record, family history, and genomic report in order to develop an overall lifetime risk estimate of six common, complex diseases. Evaluation of student performance shows significant learning gains in key content areas along with a high level of engagement.

Key Words: *Complex disease; genetics; genomics; pedigree; serious game; high school biology; interactive game; computer simulation; disease risk.*

○ Introduction

"Touching Triton," an online activity focused on conceptualizing complex disease risk (http://hudsonalpha.org/education/touchingtriton), falls into the category of "serious games" (a genre of games with a specific educational focus, usually developed to address specific learning targets). One of the best-known serious games is "Oregon Trail," which has been used in classrooms for decades as a way to engage students in issues that pioneers faced when traveling across the United States. Like that game, Touching Triton is designed to engage students in learning through a gamelike interface. Instead of pioneer America, Touching Triton is set in the planning and launch of a long-term mission to Triton, Neptune's largest moon.

Touching Triton is designed to engage students in learning through a gamelike interface.

Students take on the role of an employee of Chiron Avionics, a fictitious not-for-profit company, where they are part of the human-resources team dedicated to ensuring the health and safety of the six-person crew already selected for the mission. Using health information in a crew member's medical record, family history, and genomic report, students determine risk estimates for a set of six common, complex diseases. These risk estimates aid in the student's ultimate goal of packing preventative and treatment supplies for the 20-year round-trip mission.

A host of virtual advisors work throughout Touching Triton to provide both procedural training and just-in-time, video-based content delivery relevant to the task at hand. The integration of advisors is a critical component, so that students are able to learn how to analyze the various forms of data while simultaneously being exposed to a variety of careers in health science and genetics.

○ Learning Concepts

Touching Triton began as a paper activity that was ultimately deemed too labor- and material-intensive to be viable in a modern high school life-science course. Originally focused on student understanding of how a complex disease is influenced by many factors, some genetic and some environmental, the program grew into a robust and engaging data-analysis activity with four primary learning concepts:

(1) Many genetic and environmental factors interact in a complex manner to influence health and disease risk.

(2) Current knowledge about genomics and risk factors for disease is ever changing.

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(3) Genomic data can be used to determine a quantitative disease risk for an individual.

(4) Personalized disease risk can inform decisions regarding lifestyle and medical interventions.

These four learning concepts were developed prior to any design or programmatic work and laid the foundation for the entire process. As development took place, students and high school life-science teachers, representing a wide demographic range, tested and provided feedback. Three pilot schools began testing aspects of Touching Triton as "wireframes" before there were any graphics to judge engagement in the storyline and user interactivity. Feedback from these early pilot groups led to changes that increased student interactions and engagement. Additional testing throughout the 3-year programmatic development cycle was conducted with over 150 students, culminating in a nearly finished product during the summer of 2013. Twenty early-adopting teachers were trained on using Touching Triton in the classroom during that summer. Early-adopter feedback has been critical in developing ongoing teacher training sessions.

As Touching Triton was developed and tested, a focus on the educational value of the activity was at the forefront. The data presentation and decision making during the student experience follows a revised Bloom's Taxonomy model (Krathwohl, 2002) that includes not only knowledge acquisition but also the critical cognitive process (Figure 1). Touching Triton meets many science education standards across the United States, including the *Next Generation Science Standards* (NGSS Lead States, 2013), by engaging students in the practice of analyzing and interpreting data (Science and Engineering Practices) as well as evaluating cause-and-effect relationships (Crosscutting Concepts). Data presented in each of the three modules must be individually and holistically evaluated in assigning medical risk for each crew member. Progressing through the Touching Triton modules, students are presented with evidence to support the concept that common disease risk is influenced by complex interactions between both genetic and environmental factors (Disciplinary Core Idea: LS3.B; NGSS Lead States, 2013).

○ Student Experience: Dealing with Data

In Touching Triton, students are provided several sets of data to analyze and assess with an eye toward identifying environmental and genetic risk factors for common, complex diseases (Figure 2). Diverse crew-member profiles were built with realistic data based on current scientific knowledge and presented in a format that mimics modern electronic health records.

Medical Records

Health information for each Argos 1 crew member is presented in an electronic medical-record format. Much as a physician or nurse would scan through a patient's medical record, students are tasked with flagging pieces of information that help inform disease risk, based on a provided list of known environmental and medical risk factors. Common diseases like heart disease and macular degeneration are influenced by many different factors, and a person may simultaneously have characteristics that both increase and decrease risk for a single disease. For example, smoking increases a person's risk of heart disease (among many other things), whereas regular exercise lowers the risk of heart disease. An in-game physician advisor helps students understand the nuances of analyzing a medical record.

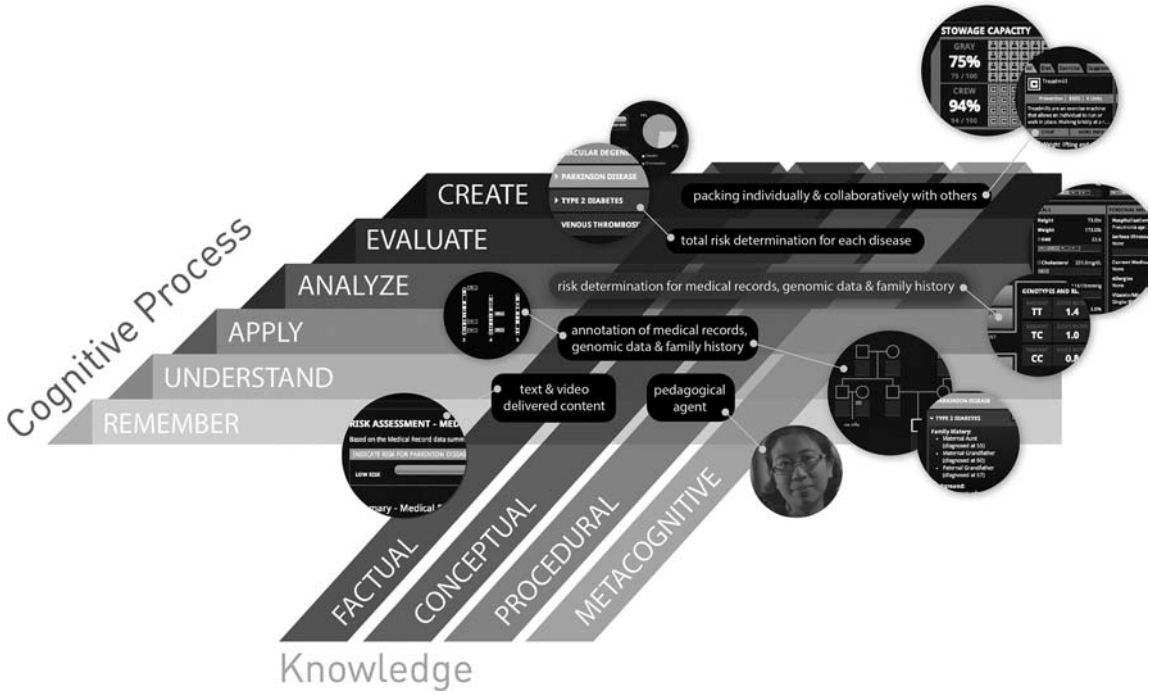

Figure 1. Intersections of Touching Triton and a revised Bloom's Taxonomy model.

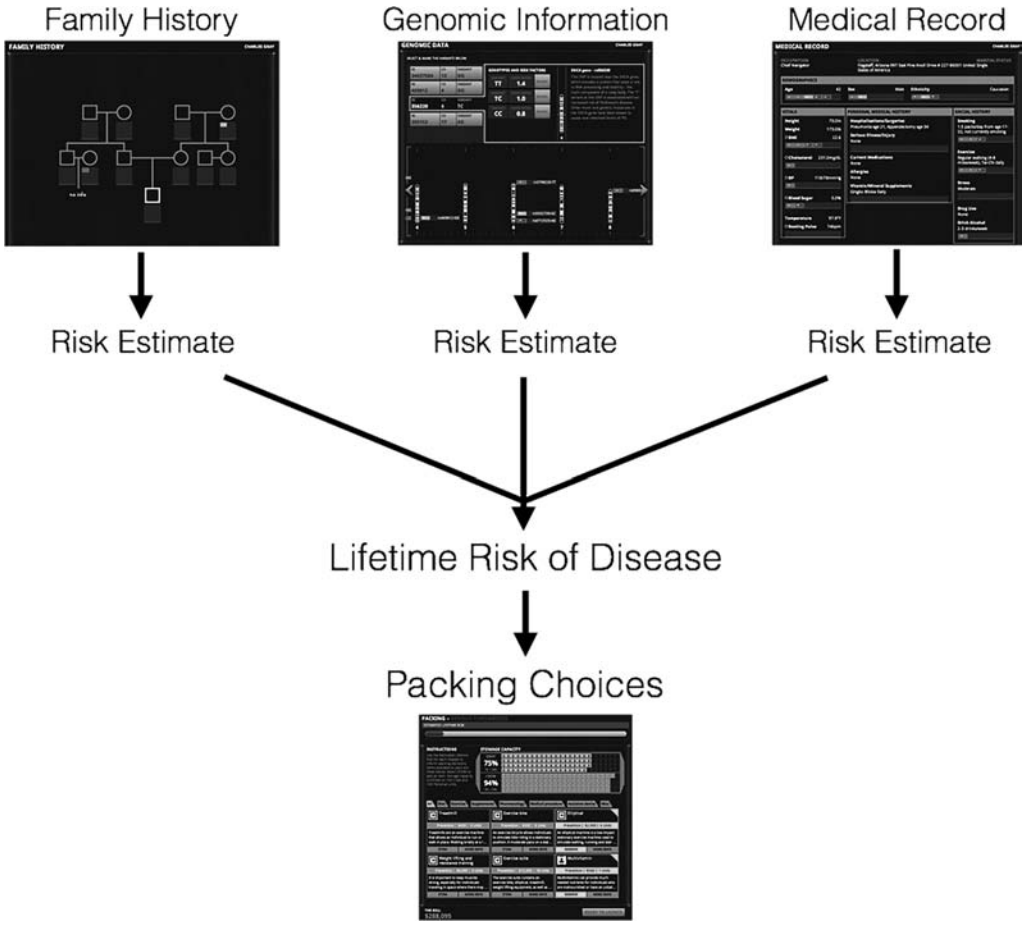

Figure 2. Data analysis and decision making within Touching Triton asks students to combine information from various sources.

Family History

Physicians often request family-history information and use it to inform disease risk. In Touching Triton, students are given family-history information about the crew member, including any family members who have been diagnosed with each condition and at what age they were diagnosed. Although complex disease risk cannot be quantified in terms of Punnett squares and Mendel's laws, family-history information can still provide important clues about risk and potential inherited risk factors. In general terms, the stronger the family history of a condition (meaning more closely related affected relatives), the higher an individual's disease risk may be. For example, having two first-degree relatives affected by type 2 diabetes increases risk more than having one third-degree relative.

Students are responsible for adding the family-history information to a pedigree, a visual representation of family relationships. Pedigrees provide a format for quickly assessing disease burden within a family. A genetic counselor functions as the virtual expert advisor, orienting students to the use of pedigrees in risk assessment. Through completion of this task, students not only learn basic pedigree structure and how to identify specific individuals on a pedigree, but also how family history influences disease risk.

Genomic Data

Students are given a crew member's genomic data report – a set of genetic variants known to influence disease risk. The variants are single-nucleotide polymorphisms (SNPs), small DNA changes common among the population. There are millions of SNPs throughout the human genome, many of which have been associated with disease. Depending on an individual's DNA sequence at a specific location in the genome, his or her risk for a particular disease may be increased, decreased, or neutral. In Touching Triton, a handful of actual SNPs have been selected for each disease to introduce students to this type of genetic variation and the complex nature of common disease genetics. Students must compare the crew-member data to population-based data and calculate a numerical risk for disease based on genomic information. The expert advisor, a Ph.D. scientist, delivers key content to help students navigate this process.

○ Student Experience: Putting It Together

Our current understanding of complex disease is ever changing and expanding. Even the most knowledgeable individual, given all available evidence, would not be able to determine with certainty whether a person will or will not develop a disease in their lifetime. However, having insight into risk for future disease may help inform current lifestyle changes and medical interventions to mitigate risk. In the real world, using genomic information to estimate future complex disease risk is in its infancy, and many risk factors

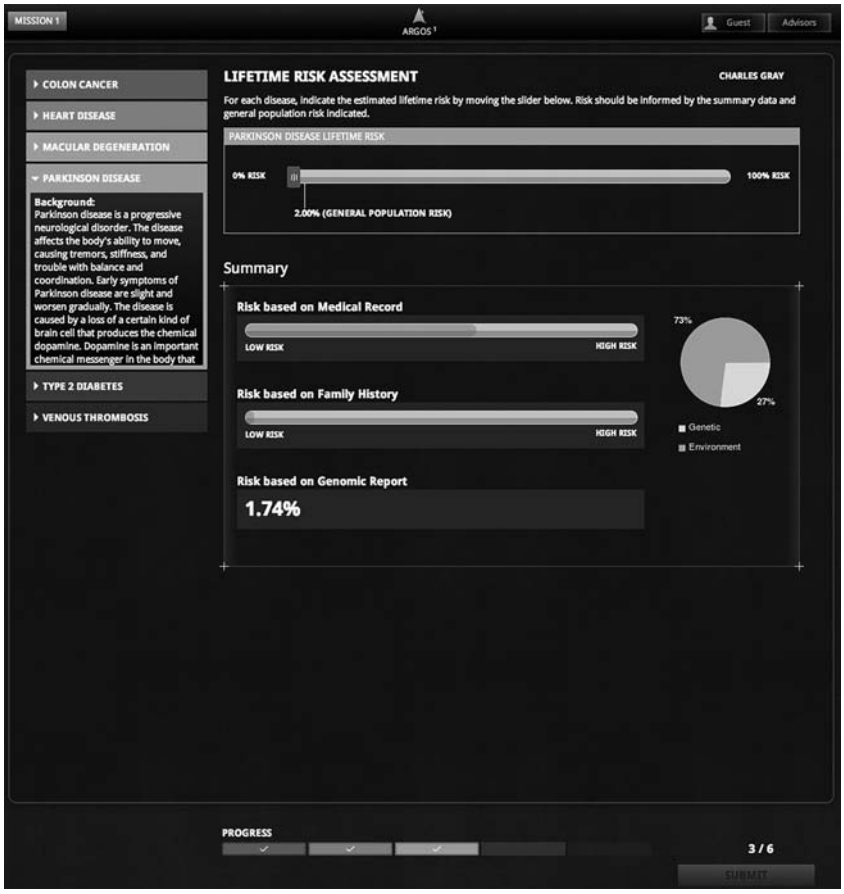

Figure 3. Lifetime risk assessment requires students to combine risk estimates from previous data analysis into one value for each disease.

and the interactions between them are unknown. However, for a group of individuals embarking on a 20-year mission away from Earth – and away from supplies and routine medical care – any available information is valuable to prepare them for what may come.

Total Risk Assessment

Once students have interacted with the three data modules, they are asked to combine all of the information to make an educated estimate of total risk for each of the six complex diseases (Figure 3). Other useful pieces of information are provided, including the general population incidence and heritability (percentage of observed variation for a trait that is explained by genetic factors) of each disease. Students are not expected to calculate an exact risk number or a "correct answer"; rather, they determine which conditions are more or less likely to occur and indicate their estimate on a slider bar from 0% to 100% risk.

Packing

After students have assigned total disease risk for a crew member, the important task of packing the Argos 1 remains. There are more than 80 packable items; some are preventative and reduce overall risk, some treat symptoms of each disease, and some have no effect on risk or treatment. These items range from genetically modified insulin-producing bacterial cultures to a colonoscopy kit to an upgraded living-quarters package. Students must decide what is most important to achieve the goal of keeping the crew alive for the entire 20-year mission. As with real space missions, students are faced with the challenge of making decisions when physical space is limited. There is simply not enough room to pack everything for every disease.

Packing is separated into two bins: one specifically designated for the crew member on which the student is currently working, and one that is shared space for the entire crew. Each packing item is predetermined as either personal or shared, challenging students to manage the space effectively. Single-player students are in complete control of everything that gets packed. Packing becomes a group activity in multiplayer mode, and the shared bin can be packed and unpacked by any other student working on the same mission. Students must interact with one another to determine what is most important to pack, leading to rich discussions about magnitude of risk and beliefs on the effectiveness of individual packing items.

Launch

"Launch" is the culminating experience, during which the student tracks mission events and individual crew members' health. The experience includes animations of each waypoint along the 20-year

mission, with flyovers of Earth's moon and Mars, flybys of Europa and Enceladus, and landing on Triton.

Launch is a dynamically generated event, and each mission is unique. The choices that students make during packing are incorporated into a sophisticated algorithm that determines whether and when crew members develop any of the six diseases. It is possible, although less likely, for students who pack poorly or pack nothing at all to have a successful mission.

○ Teacher Experience

To take full advantage of the Touching Triton activity, educators are encouraged to create free teacher accounts. The teacher portal gives educators the option to create classes, assign students to missions, monitor progress, and assign readings from HG Helix (see below).

Class Creation & Mission Setup

Touching Triton is designed to provide teachers the flexibility for a range of implementation options. Classes can be divided in multiple ways across one or more missions, depending on the needs of the individual teacher. A "mission" is defined as one instance of the activity that can be completed by one or more students working alone or collaboratively. The work can be done in or outside of class. Students working on the same mission can work discontinuously at their own pace without affecting other students' progress, although the option to launch is not available until all crew members within a mission are complete. Early-adopting teachers were able to completely set up classes and missions easily and within a timely manner (30 minutes or less).

Monitoring Student Progress

Touching Triton allows teachers to monitor students' progress in real time. Student progress through each module, student-written notes, and checks for accuracy are visible in the teacher portal within seconds of submission. This on-the-spot information gives teachers opportunities to redirect distracted students, provide immediate feedback, and ask probing questions as students progress through individual modules.

Grading

Although student responses in each module are flagged as correct or incorrect, teachers are encouraged to view the activity holistically in assigning grades. Given the subjective nature of assigning disease risk, Touching Triton does not assign a traditional grade to student work. When presented with the same data encountered by students in the modules, experts in human clinical genetics provided a wide range of risk assessment, confirming both the subjectivity and the still evolving nature of these assessments. Comparisons between expert analysis and student evaluation of risk are available to both teacher and student. Teachers view these data through the teacher portal during real-time monitoring, whereas students are presented the data at the completion of a mission. Students are not expected to match expert evaluations, but the data are included to enrich and scaffold further conversations about students' personal conceptions of risk.

○ Activity Format

Early conversations with experienced high school educators indicated that a successful digital product could not require more than one to two class periods to complete. Reports from pilot schools as well as early-adopting teachers confirm that most teachers use either one 90-minute block period or two 45-minute class periods to conduct Touching Triton. This makes the activity more easily integrated into an already packed curriculum.

Increasing access to the activity was another important consideration. To make Touching Triton available to as many students and educators as possible, the program is offered online at no cost. Touching Triton was programmed using HTML5, making it compatible with PC, MAC, Apple iPad, and Android tablet devices. Funding from the National Institutes of Health Science Education Partnership Award, Lockheed Martin, and HudsonAlpha Institute for Biotechnology has been used to create the activity and provide professional-development opportunities for teachers.

Access to the program is important, and so is access to background information for students and teachers. To that end, HG Helix was created (http://hghelix.hudsonalpha.org). HG Helix is an online web portal for public, student, and teacher audiences that contains information related to Touching Triton activity content. HG Helix is easy to read and includes related media, allowing users to gain content knowledge in multiple ways. Other features include the ability to highlight sections, take notes, and bookmark specific topics. Teachers may also assign individual reading passages to students.

○ Analysis & Results

A comprehensive evaluation of Touching Triton was begun during the 2013–2014 academic year. During the summer of 2013, 20 early-adopting teachers were trained on the use and implementation of Touching Triton within their high school life-science classes. Each was given the opportunity to participate in evaluation through pregame (Pre) and postgame (Post) student surveys that included demographic, content, and attitudinal questions. Additionally, educators completed a survey after implementation, took part in an interview, and opened their classes to observation. The multifaceted approach to evaluation of Touching Triton has provided valuable insight into its effectiveness.

Of the 20 early-adopting teachers trained in 2013, 16 teachers from 12 schools (n = 875 students) participated in the evaluation of Touching Triton during the 2013–2014 academic year. Matched-pair responses from the Pre and Post surveys yielded 594 completed evaluations used for analysis.

Two indicators of Touching Triton's success in the classroom are the student's knowledge and interest in science gains. Students engaging in Touching Triton were asked to indicate their interest in science and their science classes on the Pre and Post surveys, using a scale of 1 to 4 (1 = not at all interested, 4 = very interested). Students showed a significantly higher interest in science and their science classes after Touching Triton (Pre: 2.63, Post: 2.76; $t_{461} = -4.215$, P = 0.000).

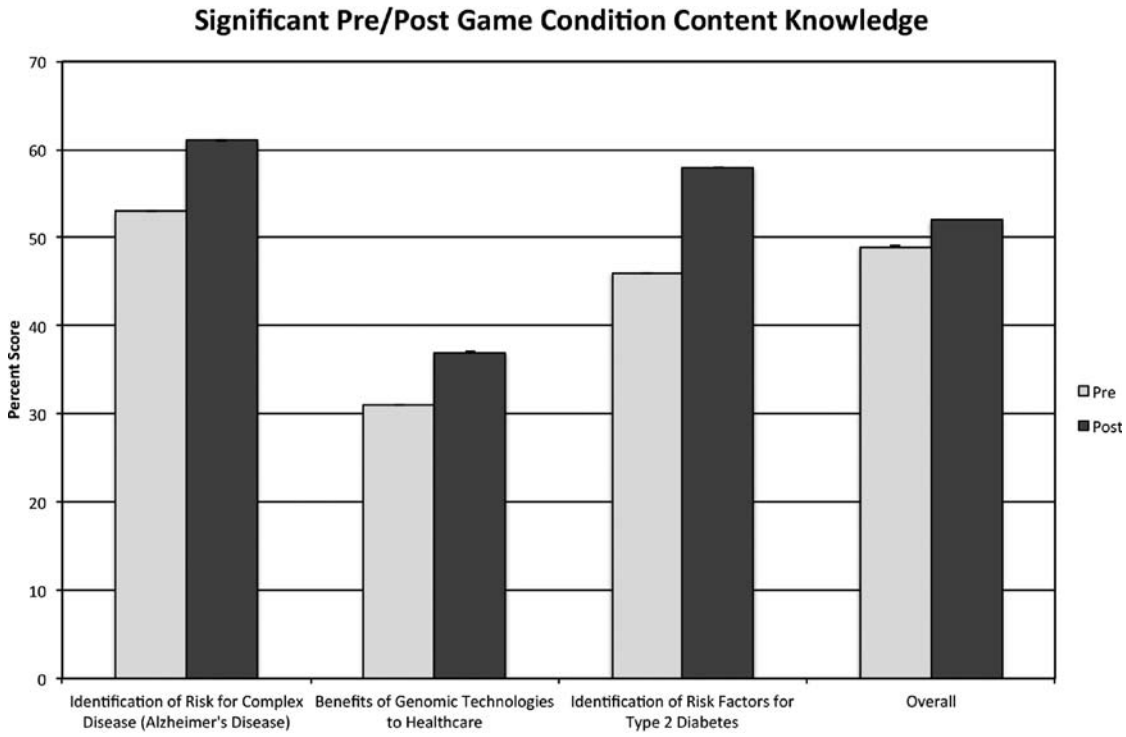

Figure 4. Significant pregame and postgame knowledge gain in four key categories, indicating that students learned foundational concepts.

Students were also asked a series of 12 multiple-choice, content-focused questions related to genetics, genomics, and complex disease. Students engaging in Touching Triton showed significant gains in content knowledge between the Pre (M = 5.87) and Post (M = 6.19) surveys ($t_{395} = -2.852$, P = 0.005). Specifically, students who engaged in the activity became significantly better at answering questions about identification of an individual's risk for Alzheimer's disease (Pre: 54% correct, Post: 61% correct; $t_{453} = -2.648$, P = 0.008) and the benefits of the current application of genomic technology to healthcare (Pre: 31% correct, Post: 37%; $t_{450} = -2.021$, P = 0.044) (Figure 4). Additional evidence of content-knowledge gain was seen in self-reported familiarity with a set of vocabulary terms. Students engaging in Touching Triton reported significant gains in 10 of 12 vocabulary terms (Pre: M = 25.47, Post: M = 28.07; $t_{413} = -16.672$, P = 0.000; Figure 5).

One challenge of evaluating Touching Triton is the scarcity of other resources and instructional strategies addressing the same content. A very early pilot test with limited numbers of students indicates that Touching Triton is at least as effective as instructor-focused activities such as lectures and reading passages. Furthermore, both students (93%) and educators (100%) stated that Touching Triton presented genetics content in an interesting format. The vast majority of students (91%) indicated that they enjoyed the activity. Educators overwhelmingly (93.75%) agreed that Touching Triton was appropriate for students ranging from introductory biology to anatomy and physiology to AP Biology courses. Evidence of student engagement and positive feedback from educators clearly demonstrate that Touching Triton is a viable vehicle for addressing complex disease risk in the classroom.

As more educators are trained through 2016, evaluation of Touching Triton will continue with this same multifaceted approach. In addition to evaluating the effectiveness of Touching Triton, a survey of medical genetics experts will be conducted to obtain estimates of risk for each disease for each crew member. As these data are collected, they will be integrated into the teacher portal.

○ Dissemination

Training for Touching Triton is being rolled out in stages. One-day trainings are being held across Alabama at five regional sites, from the fall of 2014 through the spring of 2016. Educators in neighboring states are also eligible to attend these trainings, which will focus on using the activity in the classroom, the science behind the modules, teacher portal tools, and implementation strategies. Interested high school life-science teachers are encouraged to visit the website (http://hudsonalpha.org/education/touchingtriton) for more information about scheduled trainings.

Full-day workshops are also being planned for national science-teacher meetings during 2015 and 2016. During these trainings, participants will initially take on the role of students, working with other educators to complete a mission. Participants will hear from genomics experts about our current understandings of complex disease and the scientific underpinnings of Touching Triton. Following lunch, participants will use the teacher tools to create classes and set up mock missions.

Educators unable to attend a training session will be able to take advantage of the online training currently in development. Online training for educators will include short text and video segments that navigate key components to setting up the activity for classroom deployment, minimizing educator time dedicated to setup. Development of these resources began in 2014, and

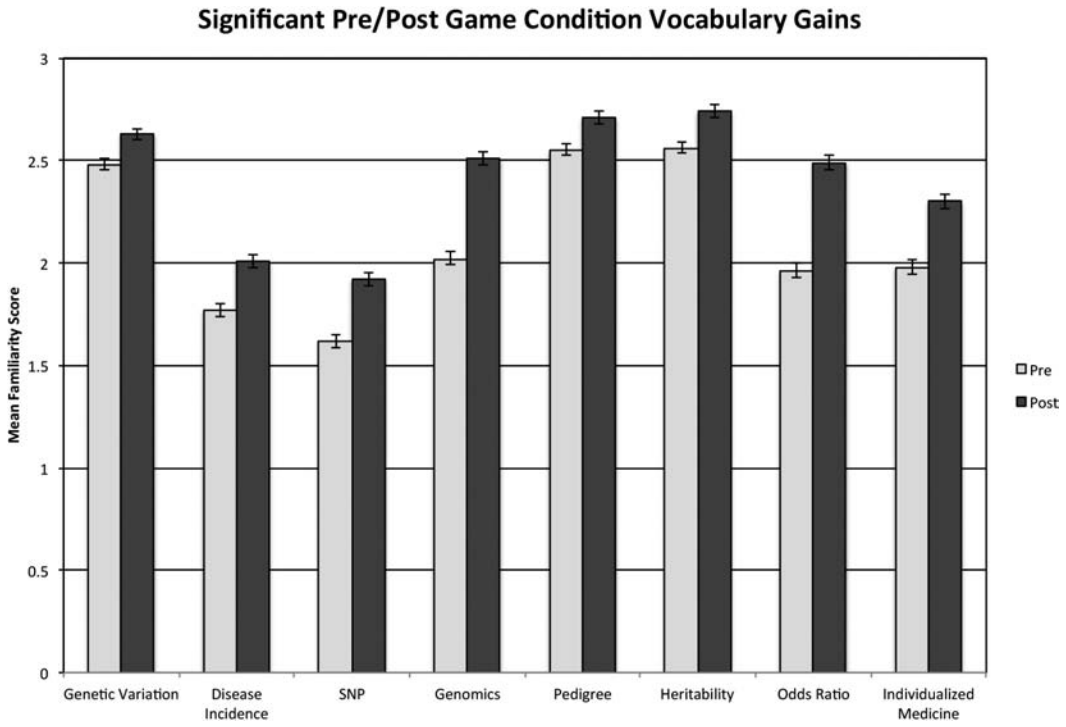

Figure 5. Significant pregame and postgame vocabulary gains across multiple terms, indicating student learning in target areas.

expansions are scheduled to occur over the following two years, to be completed by the summer of 2016. The goal of the online training is to provide educators with the scaffolding needed to successfully implement the activity.

○ Conclusions

Touching Triton immerses students in analyzing multiple data points related to human health. Student data support that the activity is engaging and a powerful tool for building related vocabulary and content knowledge. As students work to keep the pioneers of a long-term space-flight mission alive and healthy, they develop more sophisticated concepts of how genetic and environmental factors may influence their own lifetime risk for common complex diseases.

○ Acknowledgments

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References

Annetta, L.A., Minogue, J., Holmes, S.Y. & Cheng, M.-T. (2009). Investigating the impact of video games on high school students' engagement and learning about genetics. *Computers & Education, 53,* 74–85.

Gee, J.P. (2005). Learning by design: good video games as learning machines. *E-Learning, 2*(*1*), 5–16.

Krathwohl, D. (2002). A revision of Bloom's Taxonomy: an overview. *Theory Into Practice, 41,* 212–218.

Lewis, J. & Kattmann, U. (2004). Traits, genes, particles and information: revisiting students' understandings of genetics. *International Journal of Science Education, 26,* 195–206.

Lewis, J. & Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance: do students see any relationship? *International Journal of Science Education, 22,* 177–195.

Mills Shaw, K.R., Van Horne, K., Zhang, H. & Boughman, J. (2008). Essay contest reveals misconceptions of high school students in genetics content. *Genetics, 178,* 1157–1168.

NGSS Lead States (2013). *Next Generation Science Standards: For States, By States.* Washington, DC: National Academies Press.

Wong, W.L., Shen, C., Nocera, L., Carriazo, E., Tang, F., Bugga, S. et al. (2007). Serious video game effectiveness. In *ACE '07: Proceedings of the International Conference on Advances in Computer Entertainment Technology* (pp. 49–55). New York, NY: ACM.

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