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COLLABORATION BY DESIGN: DEVELOPMENT OF A VIDEO GAME FOR ENERGY LITERACY

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University students, faculty, and staff from science, engineering, education, entrepreneurship, and design (SEE(E)D) backgrounds developed a video game to leverage outreach efforts promoting sustainability, science, technology, engineering, and mathematics ((S)STEM) to underserved students. This was accomplished by transforming a board game—previously developed and used to teach elementary students about complex and often misunderstood energy and sustainability issues—through a collaborative design process. The process of taking a tangible board game into the digital realm required significant design and pedagogical adaptations to maintain student learning outcomes and content delivery. Scientists, educators, and designers strengthened the graphical and pedagogical aspects of the game collaboratively to ultimately expand and deepen the energy literacy of elementary school students. This design case seeks to elucidate the multidisciplinary collaborative design process used by SEE(E)D faculty and researchers as well as students to redesign a board game into a didactic video game that is easier to both deploy and disseminate for the benefit of K-12 students and teachers.

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Margaret Mohr-Schroeder is a Professor of STEM Education and Associate Dean in the College of Education at the University of Kentucky. Since her arrival to UK in 2006, she has been involved in over $17 million in NSF and state funding, helping to expand research and broaden participation in STEM Education. One of her current awards was recently recognized by NSF as a Top 5 model for broadening participation. Her research interests include the transdisciplinary nature of STEM education and how they can be applied to innovative preservice teacher education and K12 school models. Further, she is interested in investigating ways to broaden participation in STEM, especially of underrepresented populations and the effects these mechanisms have on their STEM literacy. Through this work, she has gained perspective on how to create opportunity and access to STEM activities to populations that normally would not have the opportunity and have witnessed and studied the significant effects these mechanisms have.

INTRODUCTION

Through a collaborative design process at the University of Kentucky, students, faculty, and staff from science, engineering, entrepreneurship, education, and design (SEE(E)D) backgrounds created a video game to increase energy literacy for elementary school students. Over the course of one year, the team took a physical board and flashcards-based game and reconceived that physical didactic tool into a digital product. Through a series of education-based design workshops involving dedicated student researchers, the game experience was translated to afford an end product consisting of a deployable prototype. The overall goal of this project was to create awareness among university students about the potential of their disciplines to collaborate and effect positive economic, environmental, and social change, for which the design and development of a video game was used as a case study. Two main objectives associated with this goal were 1) to integrate sustainability and energy awareness into a video game designed to enrich science, technology, engineering and mathematics (STEM) education outreach efforts; and 2) to involve students in the production and use of a tool to promote sustainability to underserved elementary students.

FIGURE 1. Game master leading STEM camp participants as they play the original board game on which the video game designed was based.

The video game was completed by working with business, education, and design students, who respectively improved the pedagogical and graphical aspects of a game devised and used to teach elementary students about energy sustainability. In addition, a business plan was created by entrepreneurship students around the development of this type of didactic tool, which ensures that this effort is sustainable from an economic perspective. The revised version of the game, which is used in (S)STEM education outreach events targeting underserved elementary students, has already reached over 1,000 students, providing opportunity and access to improve (S) STEM learning outcomes.

CONTEXT

From its inception, the design and development of this videogame intends to be a truly multidisciplinary collaboration, leveraging the wide-ranging expertise that exists at a large state institution of higher education. Drawing on these rich resources, the design and development of the game is process-driven by Radtke, Santillan-Jimenez, and Mohr-Schroeder, with the success of this endeavor depending on the collaborative work of these researchers and their students. The original physical board game was created by Santillan-Jimenez, a member of the team who is a research scientist at the University of Kentucky (UK) Center for Applied Energy Research (CAER) where he conducts biofuels research. In addition to research and experiential teaching, CAER has a mission to serve the state and engage with the local community. One avenue CAER personnel use to achieve this goal is by both hosting and visiting local schools to educate K-12 students about energy-related projects and concepts. Students are able to meet scientists in person and interact with them through hands-on activities. For example, scientists working on power generation actively engage students using a miniature electric generator. However, the research scientist working with biofuels was challenged by the fact that his research involves high temperatures and high pressures of explosive gases, which is not conducive for hands-on K-12 student interaction. Seeking to provide an engaging experience, he created a game board and flashcard-based activity to interactively teach students about the transformation of different starting materials to fuel and about the economic and environmental costs associated with this transformation. This was a simply structured "choose your own adventure" type game based on a decision tree that students could navigate by making decisions when presented with several choices ranging from selecting a starting material to its transportation and processing.

ORIGINAL GAME DESIGN EXPERIENCE

The overall gameplay concept is based on a student, a group of students, or multiple teams of students striving to accumulate the most points. In a classroom setting, students are typically divided into teams, each team is assigned a board and a game master, and a friendly competition ensues as teams try to achieve the top score. In its original design, the intention was for the game to be adaptable to various configurations and settings, i.e., allow for both single and multiplayer use; however, the game was most often deployed in the aforementioned way in either classrooms or science fair/camp-type settings. Each individual or team is given five "lives" or chances to navigate a game board showing several paths available to transform different starting materials into fuels. The game board has three starting points: a biomass source, a domestic oil field, and a foreign oil field. Each team must start at least once from each of these stations. With the remaining two "lives" students can start at any starting point. From the aforementioned starting points, the paths students follow depend on decisions they are prompted to make along the way, students being able to ask for clues and information to guide their decision-making process. Each "life" is accompanied by 10 initial points. As students advance through the path, points can be lost or gained depending on the environmental and the economic consequences of their decision (e.g. if a decision causes carbon pollution and/or costs money, points are lost, and if a decision avoids carbon pollution and/or saves money, points are gained). Whichever student or group of students has more points at the end wins. By the end of the game, students realize that (i) there are no perfect solutions; (ii) even the best decisions have associated costs and environmental impacts; and (iii) there are tradeoffs between the latter.

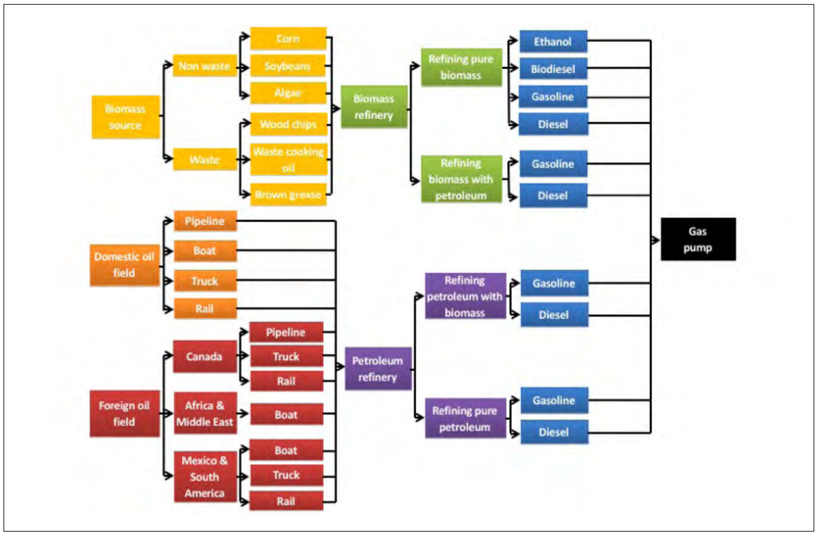

FIGURE 2. Original decision tree-based board game design. Players begin on the left and progress to the right, the route followed depending on decisions made at each stage.

Now it's your turn to decide how you would transport the crude oil to a petroleum refinery where it will be converted to fuels.

Pipeline	Boat	Truck	Rail
Pipelines are the most efficient way to transport crude oil, so you gain 3 points. However, their construction and operation cost money and emits carbon dioxide, so you lose 2 points.	Boats are the second most efficient way to transport crude oil, so you gain 2 points. However, in order to function they burn considerable amounts of fuel which cost money and emits carbon dioxide, so you lose 2 points.	Trucks are the least efficient way to transport crude oil, because they have very limited capacity and to function they burn a large amount of fuel which costs money and emits carbon dioxide, so you lose 2 points.	Trains can transport large amounts of material across long distances, so you gain 1 point. However, to function they burn considerable amounts of fuel which cost money and emits carbon dioxide, so you lose 2 points.

Now you can continue to the **Petroleum refinery** where you can think about what type of fuel can be made from your domestic crude oil.

FIGURE 3. Sample script used by the game master to guide players through the board game and keep track of points gained and lost.

As an example of playing the game, if students choose to start at a biomass source at the very beginning of the gameplay, they are told that when biomass is planted, grown, and harvested, fuels are combusted, which emits carbon dioxide, so they lose a point. In addition, producing biomass also requires water, fertilizers, labor, and other things that cost money, so they lose one more point. However, plants consume CO_2 as they grow, so they gain three points. This exchange of points happens at each decision level in the game, so students understand the impact of the decisions they have made. Each step is accompanied by an explanation that tells students the reason they are gaining or losing points. By giving students five "lives" and allowing them to complete the process five times, students strive to improve their score by applying the lessons learned in previous attempts, which reinforces the concepts taught and increases their energy literacy. This allows them to understand the relevant principles involved and make a more informed decision, for example, by avoiding transporting materials long distances as this requires fuel that costs money and emits CO_2. Students become more knowledgeable and competitive each round and learn how to be more strategic in gameplay. They often move much more quickly as they progress and need less assistance consulting the flashcards. An adult can play the role of game master and guide the gameplay to keep students engaged in the game and ensure they make educated decisions with the help of the flashcards—as opposed to speeding through the board making impulse choices simply hoping for the best.

What the researcher intends a result of the game are opportunities for students to be exposed to important sustainability concepts. For instance, they try to understand the differences between fossil fuels and biofuels to realize that biofuels are not only renewable but that they can also close the carbon cycle and reduce the carbon emissions that cause global warming. This represents a fair amount of information of a considerable degree of complexity, which means that every effort of the game design was to explore how to help students understand the material fully and in an age-appropriate manner.

The research scientist presented this game to over 550 K-12 students participating in different initiatives, including Scientists in the Classroom events, STEM/Energy nights associated with statewide Mathcounts competitions, the UK STEM Summer Camp, and a number of Energy Fairs and Science Nights. This allowed him and his team of co-workers and college students to play the game countless times with over a hundred small groups of elementary students. While noticing that students were learning quickly and effectively about energy and (S)STEM concepts through the board game, the research scientist also realized that the physical nature of the game was limiting its reach. By creating a digital didactic tool, he could expand the impact of the game to a much broader audience reaching beyond the confines of the immediate community. Indeed, a video game could reach many more students and not limit the impacted population to those students who could be hosted or visited by CAER personnel. However, the design and development of a videogame also provided an opportunity to add education, design, and business expertise to his team to reinvent how the game is played and afford a more effective and engaging teaching tool. Because of the countless hours of hands-on experience playing the game with students, the team was able to start the project with an abundance of user feedback at the beginning of the design process.

DESIGN PROCESS

University science, education, design, and business students were engaged in this effort through courses, studios, and outreach activities taught and directed by scientists, educators, and designers. Students acquired the necessary science, pedagogy, and design knowledge and applied it to the development of an improved version of the game, one with enhanced graphical and didactical elements capable of increasing the effectiveness with which the material is taught to elementary students. In this way, students at the college level were also made aware and acquired a deeper understanding of sustainability issues, all while gaining a new appreciation of the importance of outreach efforts and how the design of a game can further these goals.

Graphic design work was started by design students taking a studio class taught in the spring semester of 2016 and was finalized during the summer of 2016 with the assistance of one undergraduate student working full time for one month. In addition, the game was aligned with the Next Generation Science Standards Science and engineering practices (NGSS Lead States, 2013). Its effectiveness was assessed by education students with the guidance of STEM education faculty in the spring semester of 2016, with pilot testing taking place at outreach events led by UK education and energy research experts. A business plan was developed by students participating in a UK venture studio, and entrepreneurs boot camp, and the game engine was developed by an entrepreneurship student (who was also an engineering student and videogame developer) working on this project for one month. Finally, minority engineering students participating in a mentoring program directed by the lead research scientist used this game in several outreach events involving students from underserved elementary schools, thus providing a means to test the effectiveness of the game design while also exposing elementary students to inspirational individuals they could identify with and strive to emulate.

Design students were tasked with rethinking the design of the gameplay over a series of workshops in a studio course. To begin, design students and education students gathered with their instructors and the research scientist to play the board and flash cards-based game. The university students quickly learned how the game worked, playing as a group as the elementary school students would in a typical educational setting. This allowed college students to empathize with and understand how students would feel and experience the physical version of the game. At the conclusion of this exercise, education and design students and faculty gave feedback and thoughtful consideration to how the

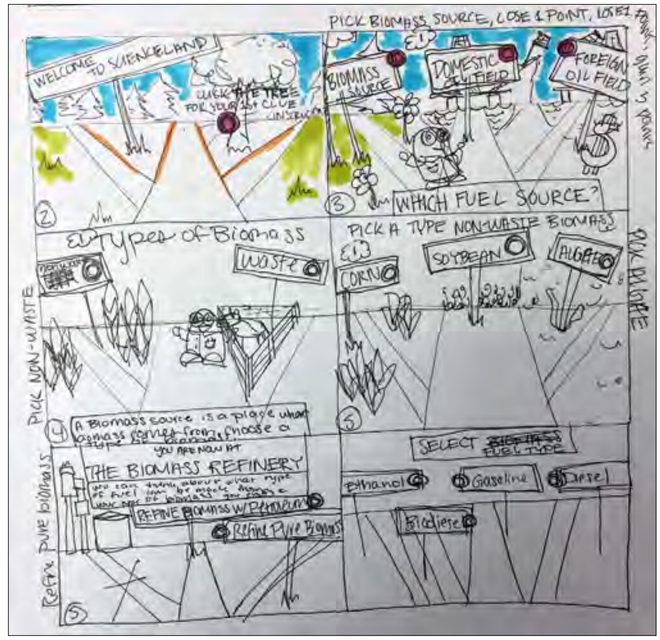

FIGURE 4. Game journey design development exploring user experience in decision making.

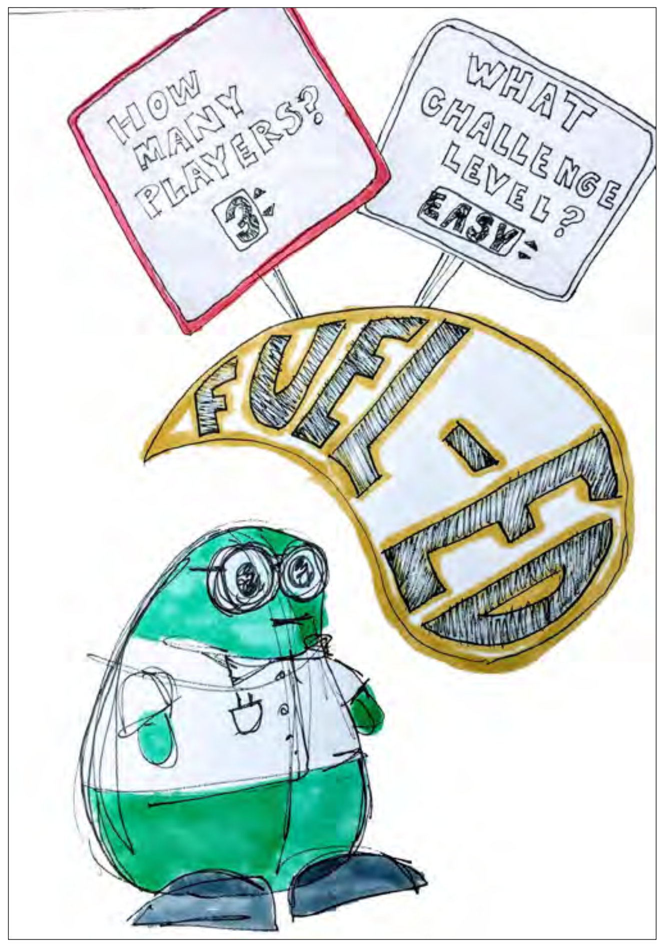

FIGURE 5. Student character development—example design of a limiting character that was later reconfigured to be more inclusive and create more of a sense of belonging.

game might be experienced as a video game. They took on the perspective of both elementary students and teachers to develop recommendations as a starting point for game design. Armed with empathy they developed by playing the game and sharing their experiences across disciplines, design students went back to their studio and worked in small groups to develop a new gameplay experience. They also gave consideration to how they would adapt it for different audiences and engage multiple players. These ideas were shared in class and were revised collectively based on an iterative design process.

Design students participating in another series of design exercises looked at character representation in the game. Students quickly sketched out designs, some envisioning the characters as children of diverse appearances to represent users, while others thought the main character should look like a scientist with a lab coat and safety glasses. Students presented these sketch ideas to the education faculty and research scientist. Both provided students with valuable feedback, mainly focused on the fact that representing a scientist in a lab coat with safety glasses would further instill in students that scientists look a certain way and limit ideas of accessibility to STEM fields. Design students quickly revised and refined their ideas based on this commentary.

The logo design was developed from a name that had been established through the entrepreneur boot camp. "Fuel-ED" was determined to be a name that succinctly conveys the content of the game and the emphasis it places on education. Design students created various sketches of how this name resonated with them after they played the game, and that could be turned into a logo. These hand sketches were shared with the research scientist, and he provided immediate feedback, which the students used to combine and refine their initial sketch ideas during their design studio. This was a rapid and effective way of soliciting feedback that kept the design students from wasting time making digital designs that were not representative of the vision for the logo. One design was selected and created digitally for the game.

This hand sketch and quick feedback mechanism was used for creating all the graphics for the game design. When a sketch idea was approved as the final approach, students then re-created their sketches digitally in Adobe Illustrator. Final tweaks to images were completed as needed—a majority of the time these changes were made because of how they appeared on the game when they were coded into the interface.

By the end of the semester, design students had experienced one combined class with education students and faculty as well as a series of in-class workshops and one field trip to CAER, to help them develop and refine their ideas. In order to maintain continuity in the project beyond the semester,

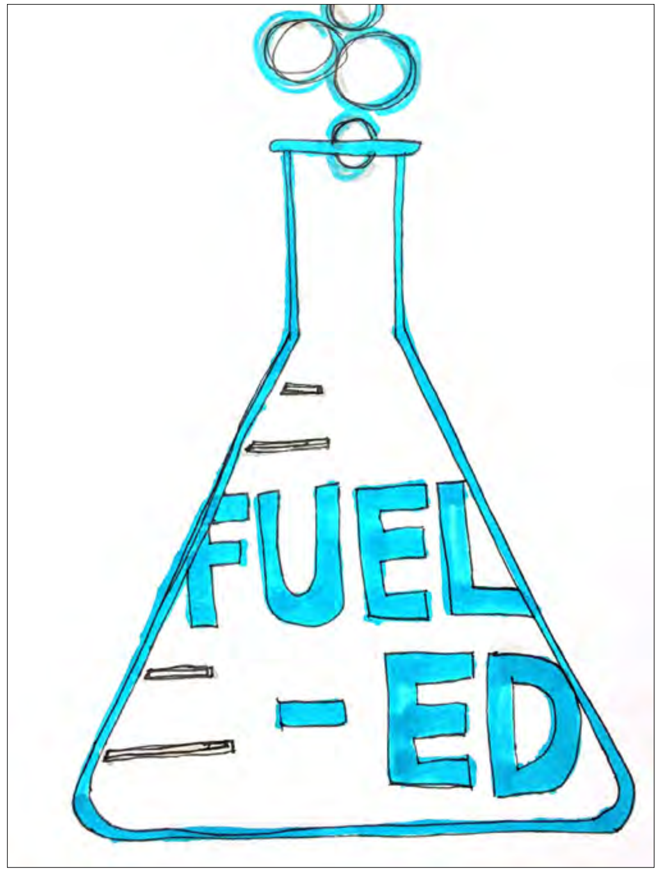

FIGURE 6. Potential student logo design development sketches.

FIGURE 7. Two student logo designs that were revised developmental sketches incorporating feedback from collaborators. These two became the inspiration for the final digital logo.

FIGURE 8. Finalized digital logo design on game home screen translated from sketches.

one student was selected to continue with the ideas produced and to finalize the graphic design concepts as a full-time undergraduate researcher. This design student met periodically with the full team to show the progress made and worked independently over the summer to create all the remaining graphics and flashcards required for the game. This was given to the video game developer, who was also an undergraduate research student who had been simultaneously working on the game engine. By the beginning of the fall semester, a working prototype had been completed. Students, researchers, and faculty were involved in deploying the video game at events, including various elementary school visits, camps, and fairs. The instructional design, which included more than just the final product, incorporated over a hundred undergraduate students in the game development. The game was only a small product of the larger instructional design that produced it.

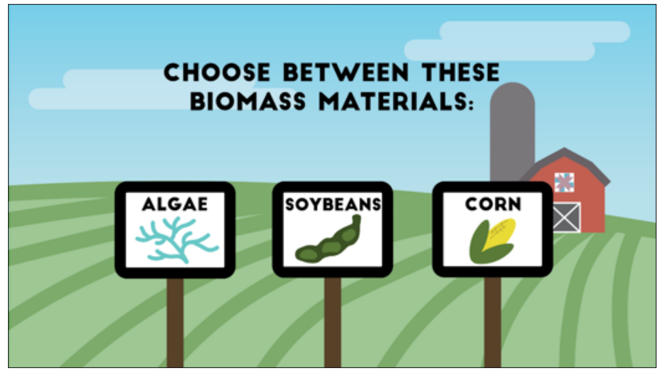

FIGURE 9. Video game screen still for biomass selection, which simplifies information for the user with basic graphics. Notice the attention to detail, such as the barn quilt on the background barn.

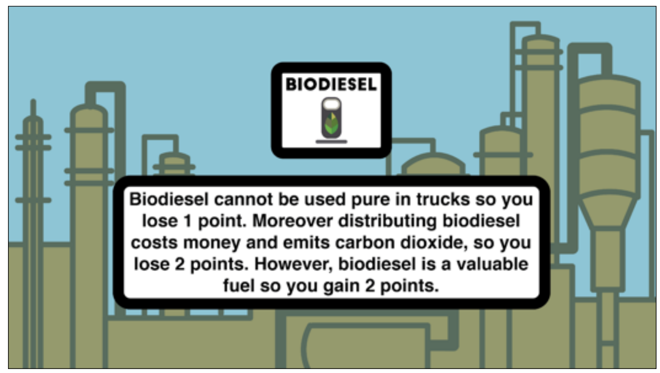

FIGURE 10. Video game screen still of pop-up information after a gamer selects biodiesel as a fuel creating a cohesive platform and layers of information. It includes information on why the gamer wins and loses points based on their decisions.

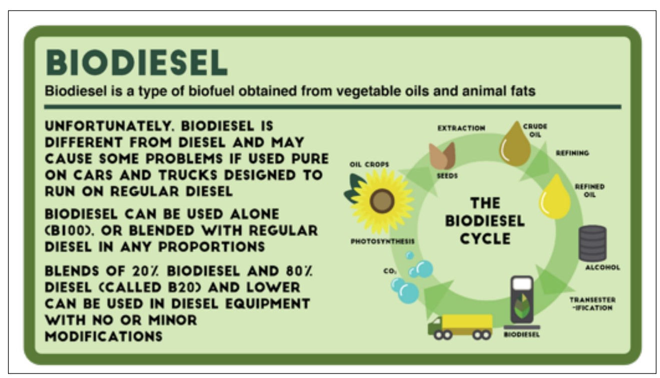

FIGURE 11. If a gamer did not understand biodiesel or wanted to learn more, they could click the question mark, and this biodiesel flashcard pops up, creating a streamlined user experience.

REVISED GAME DESIGN EXPERIENCE

The video game developed is currently designed to operate in a guided manner, allowing an adult—who could be a teacher, teaching assistant, family member and/or a researcher or college student volunteer—to direct the game as a group of K-12 students play, which is analogous to the way in which the original game was played. Using the same principle behind the original board game but rethinking the experience, the video game flows through a series of screens rather than displaying the whole game board at once, as was the case in the physical version. The video game has graphics that represent each concept, which creates an experience that visually connects students to the subject matter. For example, when students are choosing a transportation method for crude oil from a domestic oil field, the background graphic is a cartoon representation of what those look like in America. For foreign oil fields, the background graphic depicts a different landscape more representative of other countries. Individual icons are used to represent the various options students can select, which both enhances the experience and provides additional ways to reinforce the options available. For strong readers, the text might be sufficient, but to create a more universal experience, the graphics provide a layered learning environment.

STUDENT INVOLVEMENT

Students involved in the development of the game came from different levels and different disciplinary backgrounds throughout the project. STEM education students, design students, and engineering students each provided a specific contribution according to their backgrounds. Engineering students provided content, expertise, and coded the game. Design students created the game interface, graphics, and user experience. Education students helped ensure the game was aligned with next generation science standards as well as game assessment. In having the range of students

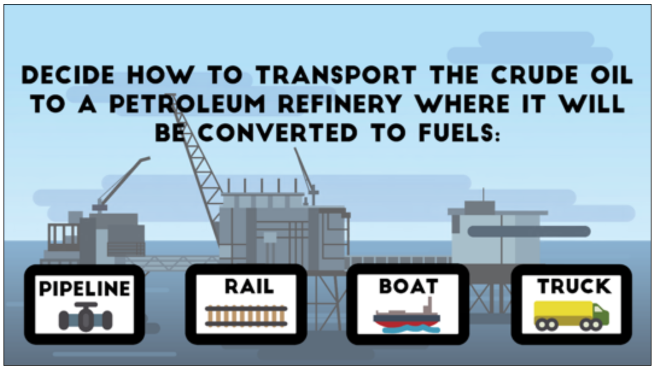

FIGURE 12. Video game screen still for domestic transportation to the petroleum refinery.

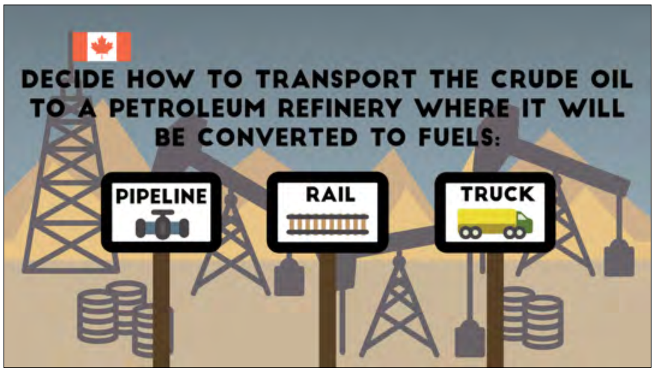

FIGURE 13. Video game screen still for international transportation to the petroleum refinery.

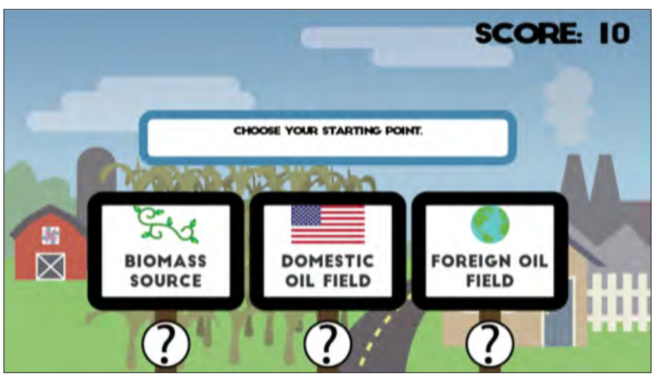

FIGURE 14. Video game interface promotes learning by giving the user more information about a specific topic. They can click on the question mark to bring up additional information about each biomass material.

involved, the project was able to develop simultaneously in diverse ways; however, it did pose unforeseen obstacles.

UNFORESEEN OBSTACLES

Because of the wide and diverse group of collaborators, working across the disciplines, we struggled with sticking to the initially projected timeline. We had challenges with establishing our expectations that were not clear as a group. Due to the lack of clarity in creating clear outcomes by

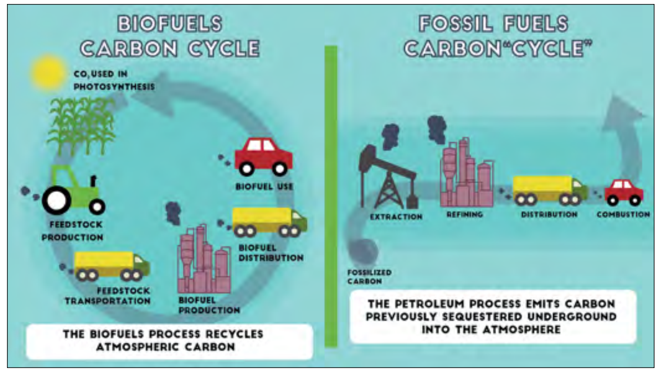

FIGURE 15. Video game screen explaining the carbon cycle.

certain dates, the outputs often didn't match our expectations and deadlines. We were dependent on one student coding over the summer, and this proved to restrict our development timeline. Struggling to stay on our timeline, we still continued to pilot they game with college students in STEM fields as a tool during outreach events to K-12 schools to be able to refine and revise our initial ideas.

UNEXPECTED DESIGN CHANGES

The student's understanding of coding greatly informed design changes throughout the process. Many changes occurred as the team's understanding of the capabilities and limitations of coding knowledge increased over time. The coding aspect of the project would then inform the next steps in the game development and the resulting design. One way this caused a design shift was through integration of flashcards into the design of the game. Originally when the game was still a board game, the flashcards were provided on a separate iPad to accompany a physical board game to provide more content-specific information. In the translation of the design to a digital version, the integration of pop-ups of flashcards was a pivot point in the game design as the student had recently learned how to code this specific element.

The intention was to have a handout to accompany the game, but we were able to develop a design that could be coded to create pop-up links that became embedded in the game. This provides an additional resource for students to learn more information about the question in the game without having to reference a different screen or handout, thus simplifying the administration of the game by educators and the user experience for the students to readily access information pertinent to the specific question.

The revised game then became self-contained with pop-up information all in one place to streamline information, therefore not overwhelming the user with all the information from the flashcards all at once. This incorporation of flashcards as pop-ups within the game created an opportunity for another means of engaging the user in deeper learning.

ASSESSMENT

Student involvement in the design and development of the video game was assessed by tracking the number and engagement of the SEE(E)D students that participated in the courses, studios, and outreach activities taught and/or used the game in K-12 STEM education outreach events. Student engagement was measured using a STEM Sustainability Engagement Instrument or STEM-SEI (Little, 2014)—which assesses a number of economic, environmental, and social items. The STEM-SEI results gave the research team evidence and feedback to ensure the SEE(E)D students were learning the intended outcomes put forward in the game design (e.g., to increase their concern about, knowledge of, and engagement with a number of sustainability issues).

The performance and impact of this project in terms of advancing economic vitality and the potential of this project to become sustainable from an economic standpoint was assessed through the business plan developed by the students participating in an entrepreneur boot camp. In terms of social equity, the impact of this project was measured by tracking the demographics of the students that were involved both at the college and K-12 levels. At the college level, this was done by collecting demographic data on all students involved using the STEM-SEI, while at the K-12 level, this was completed by using publicly available demographic and free or reduced lunch data corresponding to the K-12 institutions that were involved.

FIGURE 16. University students testing video game prototype.

FIGURE 17. Elementary students are testing video game prototype.

ADDRESSING CHALLENGES

The main obstacle to overcome for the team came from different disciplines at different levels, such as faculty, researchers, school teachers, students, and elementary school students, and finding guiding and aligning principles across disciplines and ages. Additionally, while the game was being developed, the next-generation science standards were rolled out statewide. This occurred simultaneously to game design, which was a moving target and, therefore, a challenge to tackle. Although this created opportunities for synergy, it also came with challenges and unintended consequences. One way the team addressed these challenges was by establishing a consistent language across the disciplines, which proved essential for a cohesive and coherent project outcome. In determining clear and effective language, it brought the students together to share input throughout the process with lots of communication between disciplines, which was an unintended consequence. The end goals of learning for the students playing the game—(i) there are no perfect solutions; (ii) even the best decisions have associated costs and environmental impacts; and (iii) there are tradeoffs between the latter— translates directly into the learning end goals for the project team as (i) there are no perfect solutions in working collaboratively; (ii) even the best design decisions have associated costs and impacts that influence project goals; and (iii) there are tradeoffs between the latter.

CONCLUSION

Involving college students in the design of a video game to increase energy literacy as a part of their coursework—as well as engaging the most interested students to develop a prototype by working as student researchers—was found for us to be an effective way to increase their concern about, knowledge of, and engagement with a number of sustainability issues. The intent of this design case is to expand the impact of this project beyond its immediate scope by providing a precedent description to others interested in developing similar tools to teach topics other than energy and/or attain other goals besides increasing energy literacy by utilizing a similar design process. Because this collaboration was so fruitful, the team continues to pursue avenues to further develop this work, as the emphasis of this project was establishing a sustainable system for the development of effective, versatile and distributable didactic tools.

ACKNOWLEDGMENTS

This project would not have been completed without the support of a University of Kentucky Sustainability Challenge Grant awarded in 2016. It is also important to recognize the contributions of the undergraduate student researchers Carter David Henning, Jessica Moore, and Hannalore Clause who worked tirelessly in creating the video game. We would also like to thank the students in the 2016 spring semester second-year interior design course who created design concepts for the logo and the gameplay as well as the STEM education students who actively engaged in the design process.

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