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## **AC 2012-4505: HIGH SCHOOL STUDENTS' HABITS OF MIND AND ACTION IN ENGINEERING DESIGN**

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# High School Students' Habits of Mind and Action in Engineering Design

## Abstract

Nine high school-aged students of different team sizes worked through an interdisciplinary engineering design challenge. The student designers engaged at various levels of problem exploration and definition. They also generated and explored multiple alternatives. The student designers drew upon their prior knowledge, analogies, and the Internet to expound the problem and develop solutions. Although the student designers felt that the problem was relevant and interesting, they did not feel that they had enough training and content knowledge to move forward with constructing, analyzing, and evaluating their designs.

## Rationale

Employing engineering design in elementary and primary school curricula could potentially benefit a broad and diverse group of students whether or not they pursue engineering as a career. It has also been proffered that engineering design has the promise of enhancing and integrating the science, technology, and mathematics content areas<sup>1</sup>. However, there are many questions yet to be answered regarding engineering design as it pertains to its role in primary and secondary educational settings. Some of those questions include: what does engineering design look like in K-12<sup>2</sup>? What do the students do and how do they think when defining and working an engineering design problem? Through this paper we will specifically explore and examine how seniors in high school approached and worked through an open-ended engineering design challenge.

## Procedures

This research was informed by basic interpretive research strategies, with a strong flavor of grounded theory. The purpose of the study was to understand how high school students make sense of engineering design as an educational activity. Hence, we employed a process informed by constant comparative techniques – the simultaneous collection and analysis of data. We deviated from grounded theory by not making the production of a substantive-level theory a requisite to the study. Rather, themes and findings in high school engineering design were derived and explained. Peer debriefing became an ongoing process following the analyses. In addition to peer debriefing, the credibility of this study was established through triangulation of the themes and findings from the design challenge, the reflective interview, and the student generated physical traces, e.g. sketches and notes.

## High school student designers

Both criterion and convenience sampling approaches were employed to recruit student designers for this study. There were two criteria: high school students who had an interest in engineering and were upperclassmen. We assumed that student designers with awareness and interest in engineering would be motivated to work through the engineering design challenge. We found this indeed to be the case with all of the student designers; they were completely engaged in the design challenge from start to finish. Upperclassmen were chosen as we assumed they would have more ability and development to help them perform engineering design than would high school freshmen or sophomores.

With these criteria, student designers were recruited from a pool of students who had participated in a university-sponsored engineering program in the summer. The weeklong

summer program was hosted by the engineering college and held at the university the summer proceeding the students' senior year in high school. An email was sent out to the program participants who lived within a specified distance from the university. As this study was an emerging design, the study evolved as new insights were gained. Therefore, only small groups of participants were recruited at one time. The participants were sent an email if they lived within a few minutes from the university. After the student designers had participated and the data was further analyzed, then participants who lived farther from the university were contacted. This process continued four times spanning a fourth month time frame. In the end, the final participants lived over one hour from the university. This process resulted in nine study participants; all of who were high school seniors from different public schools throughout the Intermountain West region.

There were a total of six females and three males. In order to gain a deeper understanding of the students' habits and thinking, a smaller number of participants was chosen. This allowed for more in-depth analyses of each design team. The summer engineering program was a selective process attracting students with high academic records. This fact was also reflected in our pool of student designers. Each student designer stated a desire to pursue a post-secondary degree in the science and engineering fields. One student designer's high school offered pre-engineering courses and had taken courses in engineering graphics and aerospace. Not all of the student designers were able to take pre-engineering coursework, as these courses were not offered at the varying high schools. None of the student designers had taken a course in engineering design or had a capstone experience.

#### The design studio

The student designers came to the university campus and met the researchers after school or on holidays. They were directed to a room with an open floor plan where tables and chairs were scattered throughout and a few cubicles lined the opposing walls. The exterior wall was a set of windows that overlooked what was normally a busy pathway. It was along these windows where the "design studio" was setup. A computer lay on top of a table with a few chairs surrounding it.

After brief introductions, the student designers were informed of the research administration. They were made aware of a webcam placed near the desktop computer to capture video and audio. A small digital audio recorder was placed next to the desktop for redundancy. The desktop had Internet access, computer aided drafting software, Inventor®, and Microsoft Office. The desktop also had software that tracked activity and movements on the computer. They were also given engineering graphing paper. The researchers stayed in the room while the students worked through the design challenge, but they were sitting at the cubicles working on separate tasks. However, the student designers were told that if they had any administrative question that they could approach the researchers as needed.

#### Lights Out!

The student designers were tasked with working through an engineering design challenge in various team sizes (one, two, and four). The challenge was centered on providing light. Although the design challenge underwent various refinements throughout the research study, the final version is given below:

## Lights Out!

If you and your family lived in an isolated two-bedroom home that experienced frequent power outages, how could you devise a system, process, or device that would provide light for your family to safely move throughout the house and perform essential tasks?

Your solution should be economical, user friendly, and safe. Please provide a sketch or wiring diagram and a prototype of your solution.

The student designers did not ask many questions regarding the design challenge once it was given to them. When the student designers were asked about the design challenge, they expressed that it was not too difficult to undertake.

Immediately following the design challenge, the student designers participated in an open-ended reflective interview. The purpose of the interviews was to probe the student designers' thinking and solicit their feedback on the design challenge. The interview questions asked the student designers to explain or further elucidate their decision making processes, strategies, problem framing, and overall experience with the challenge. Some of the interview questions included, "What did you see as the problem?" and "You talked about lots of different things, why did you choose this solution?"

### Themes and findings

Through the analysis, various themes and findings emerged. The analyses imply that engineering design may be a viable part of high school pre-engineering curricula. However, there are certain activities and limitations that must be overcome for high school students to design successfully.

"Basically, the problem is, uh..."

Very often students are given a problem with the accompanying requirements and constraints. From these problems, students typically generate a single correct solution. Open-ended problems, like this design challenge, allow for a more thorough exploration and formulation of the problem. Hynes, et al.<sup>3</sup> assert, "High school students are capable of identifying a need or problem in a given situation and should be provided the opportunity to do so." The student designers in this study used various approaches and formulated the problem differently.

Below is a description of how one team of student designers approached the problem. This team consisted of two males, Eric and Braden (pseudonyms). As I handed them the design challenge printed on one sheet of paper, I told them there is no right or wrong answer. As soon as I gave Eric and Braden the design challenge description, they quickly turned their focus to the paper. Even as I brought the paper over and laid it down in front of them on the table, their eyes were fixated on the challenge. From this point forward, I am not sure they heard what I said as they were focused on the design challenge scenario and read it quietly for a couple of minutes. I further stated that they were to read the challenge (they were already reading the challenge anyway) and work as extensively as they wanted. I let them know that I would be over in my cubicle and could ask me questions as they arose. Braden gave me a quick glance and then quickly returned to his reading. I later placed a large stack of engineering graphing paper, a

pencil, and pen next to Braden. The snacks were located on the left of the monitor in front of Eric, and the mouse and writing accoutrements were on the right of the monitor where Braden was seated. As they finished reading and rereading the challenge, Eric and Braden looked up and slid back in their chairs, perhaps to signal to each other that they were ready to move forward.

Braden: Okay. [pause, both looking down at the design scenario] It's pretty uh...

Eric: So, what do they want us to do? I don't really get it.

B: Basically, the problems is, uh...

E: We have power outages

B: Power outages. How can we stop that? That's pretty broad.

[Eric breathes a slight snigger in agreement]

B: A pretty broad subject, um

E: You got everything from just like just your house power or like power lines downed from trees. Lotsa' crap.

[Braden reaches for a pencil]

B: How about we write down all the ways that we can think that your power would go out

E: Downed power lines

B: How does that happen?

E: Storms, trees...

[Braden began to write down all of their ideas on a sheet of paper]

It appears from the above interaction that this team perceived the problem to be power outages in general, rather than dealing with the lack of light from the power outage.

Eric and Braden went on to brainstorm how they would mitigate all the different types of power outages. Eventually they turned to Google to validate their ideas and solutions. Their conversation evolved into a political discussion and government intrusion. The team became visibly exasperated and Eric declared, "This doesn't have anything to do with engineering, this is all government!" At this point Eric and Braden both looked up from the computer monitor and went back to the design challenge brief. After rereading the challenge Eric stated, "Protect your own home, not the whole nation." From then on, Eric and Braden narrowed their focus to minimizing the impact of power outages on a small house rather than improving the complete power grid.

Eric and Braden briefly looked at the problem and recognized its ill-structure, but they then quickly turned to generating potential solutions. When their approach became unsatisfactory, they returned to the design challenge brief for clarification. They were not the

only team to take this approach. All of the student designers proposed ideas and returned to the design challenge brief to refocus their efforts. The team of four females, Carla, Danielle, Eileen, and Faith quickly read the challenge and began listing ideas, including solar and wind. Unsatisfied with their approach, they returned to the design brief.

Carla: A two bedroom... that is small. So it doesn't have to be a huge amount of power supply either.

Faith: How many... device, system, process. ahh.

Carla: So it looks like we're only providing light.

Danielle: No we're... it says...

Carla: Will provide light

Danielle: But for essential tasks, I mean.

Carla: Well I think it means lights or essential tasks. So if we move around the house and perform...

Eileen: Yeah. I think it's just light.

The student designers superficially recognized the problem, but then quickly jumped to brainstorming solutions. Even though the student designers returned to defining the problem, their first habit was to brainstorm solutions. Dym et al.<sup>4</sup> suggested “we spend more time thinking about how we define the problem, rather than on the solution to the problem.” It is not certain why all of the student designers began with brainstorming, but that approach is frequently taught in design, whether or not it is effective. Jonassen<sup>5</sup> proffered a distinct model that describes the engineering design process beginning with the formulation of the problem, with the accompanying constraints and specifications. This iterative design model is similar to the substantive level theory of the coevolution of the problem and solution spaces developed by Maher and Tang<sup>6</sup>.

Each student designer spent time gathering information. Most of the information gathering was performed on the Internet using the Google search engine. One of the student designers, Braden, stated, “Google is the best site ever!” However, the student designers did not go directly to the Internet to brainstorm; they only went there to verify, expound upon, and seek for additional ideas. When they became stumped by a question on hydraulic systems, Danielle suggested that they do an Internet search,

Eileen: Can we create enough just from a water circulatory system?

Carla: How much power can they --

Eileen: Depends on how efficient.

Danielle: What do we search on that?

Student designers feel comfortable using the Internet for acquiring information, as it has become part of their everyday lives. The question is not if the students will use search engines, but how they will use them if they are available?

“That’s a funny idea!”

The students were able to consider and explore multiple design alternatives. The students were able to draw upon analogous experiences in lieu of professional expertise to better understand and expand their designs. The number of alternatives generated and explored varied amongst the teams. The concept maps discussed later are indicative of this. The team of four females generated nearly 30 alternatives and explored seven of them in depth, while the rest of the teams generated around 10. Nevertheless, there was an overlap of the ideas. All of the teams considered alternative fuel, solar, and wind. Three ideas were shared across different teams: backup generators, batteries, and stationary bikes. Two of the teams mentioned glow-in-the-dark paint. Some of the ideas were perceived as being “funny” but they stimulated conversation and thought that led to viable option.

#### Authentic

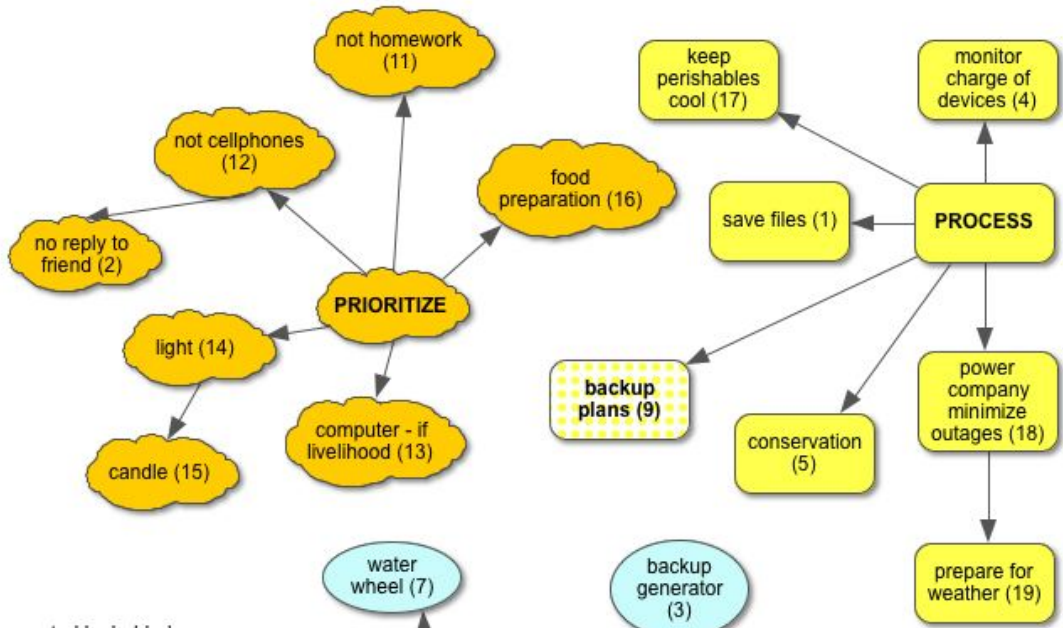
The student designers stated and found the design challenges authentic and relevant to their everyday lives. The student designers did not even take opportunities to leave the work area to eat, answer cell phones, or use the restroom. Perhaps this could have been done out of respect or propriety, but following the challenge, each student designer expressed that the challenge was “real world” and that it had application to their everyday lives.

All of the student design teams struggled with the ill-structured nature of the challenge. Eric went on to say, “I hate problems like this.” However, Braden chided Eric and stated that in order to have a realistic design problem, it had to be broad. Douglas, et al.<sup>7</sup> found that engineering students faced discomfort with open-ended engineering problems as well.

#### Concept Maps

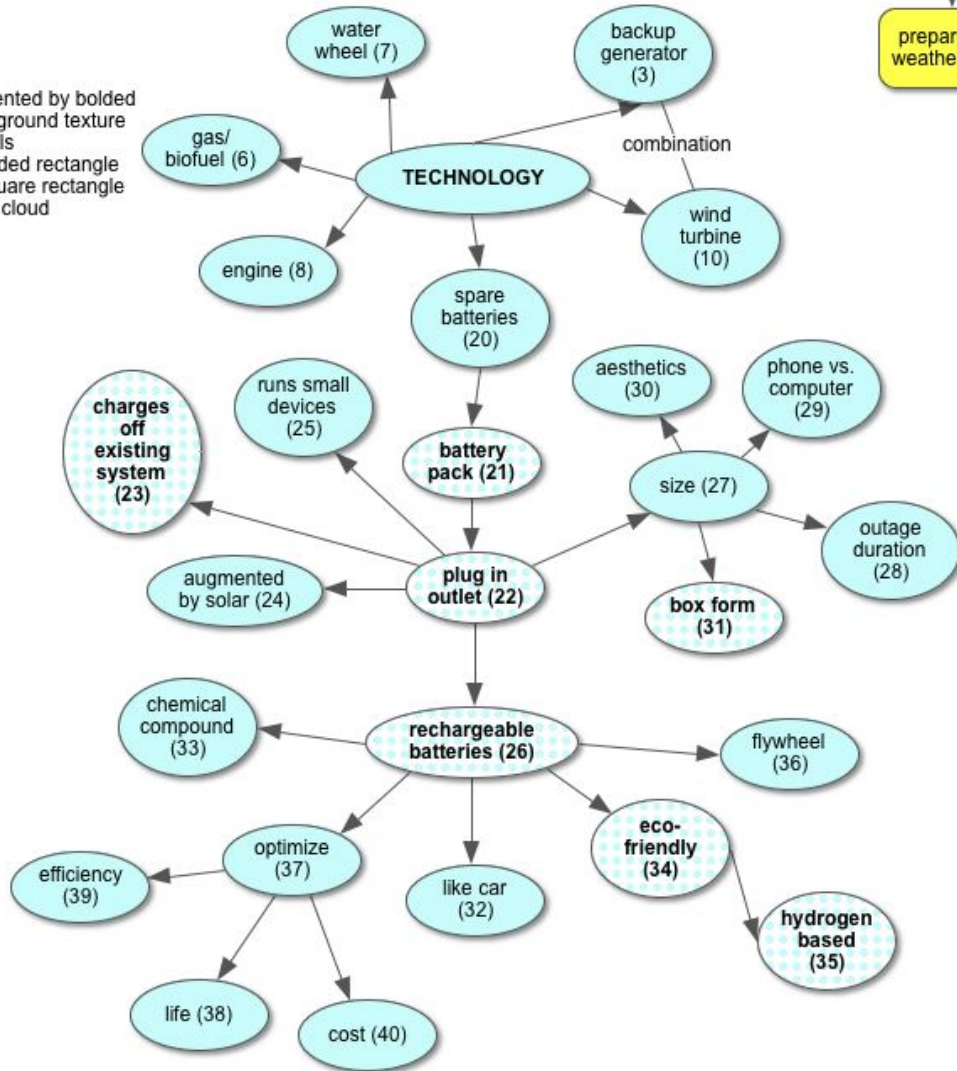
Concept maps may be used for evaluating and assessing student work<sup>8</sup>. The concept maps may be student generated or they may be produced by a teacher or researcher. These maps can contain a great deal of information. They lend to thematic analyses, can tell a story, and force the researcher to make connections. The majority of the themes generated in this research study were derived and further explained from the researcher generated concept maps. Concept maps for all of the teams are pasted below.

From the concept maps, different design strategies were apparent. All of the teams, with the exception of the team of four, considered non-technical issues such as prioritizing what is needed when the power goes out, the causes of the outages, and processes that might be enacted to reach a solution.

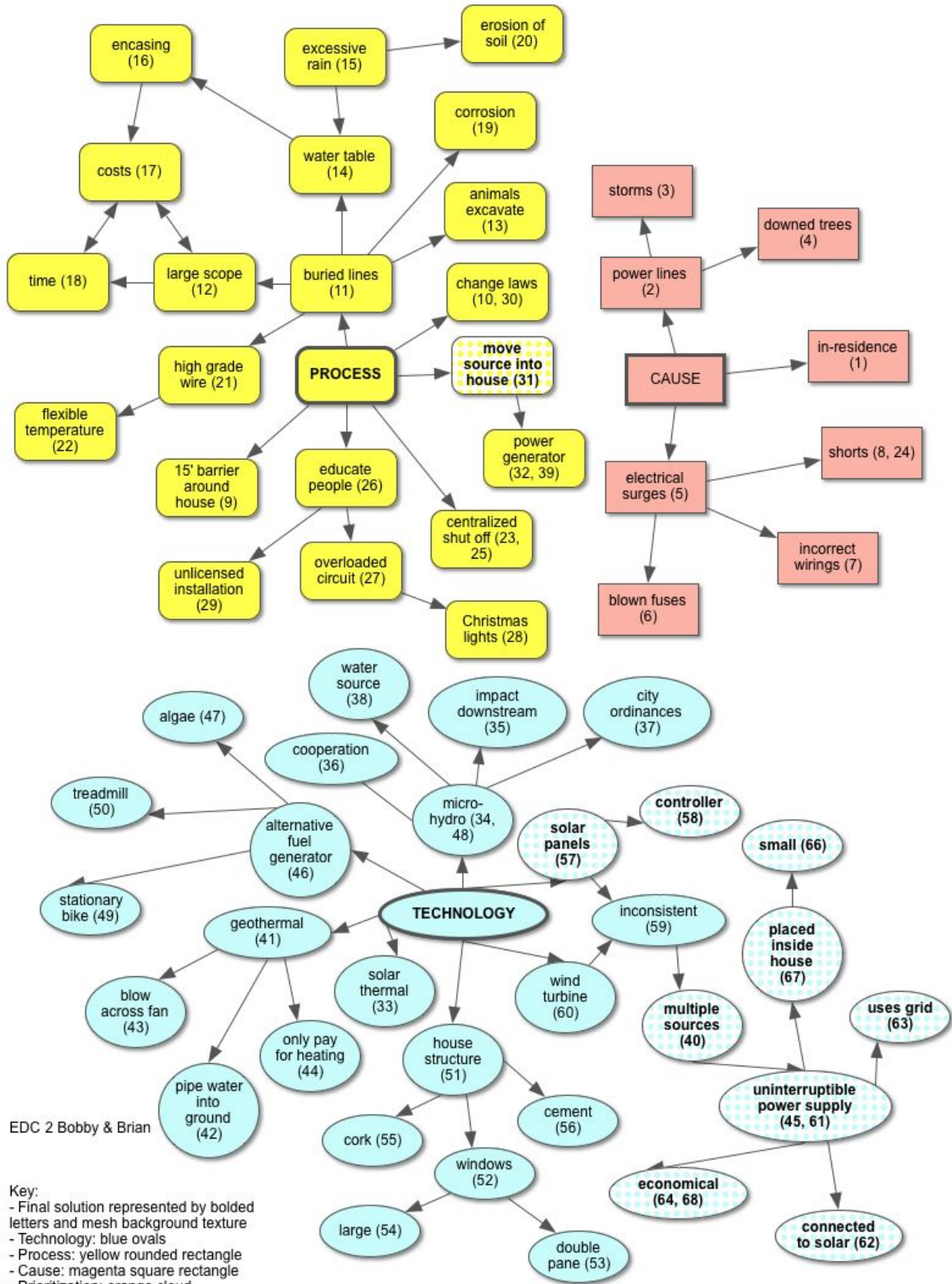


EDC 1 Adam

- Key:
- Final solution represented by bolded letters and mesh background texture
  - Technology: blue ovals
  - Process: yellow rounded rectangle
  - Causes: magenta square rectangle
  - Prioritization: orange cloud

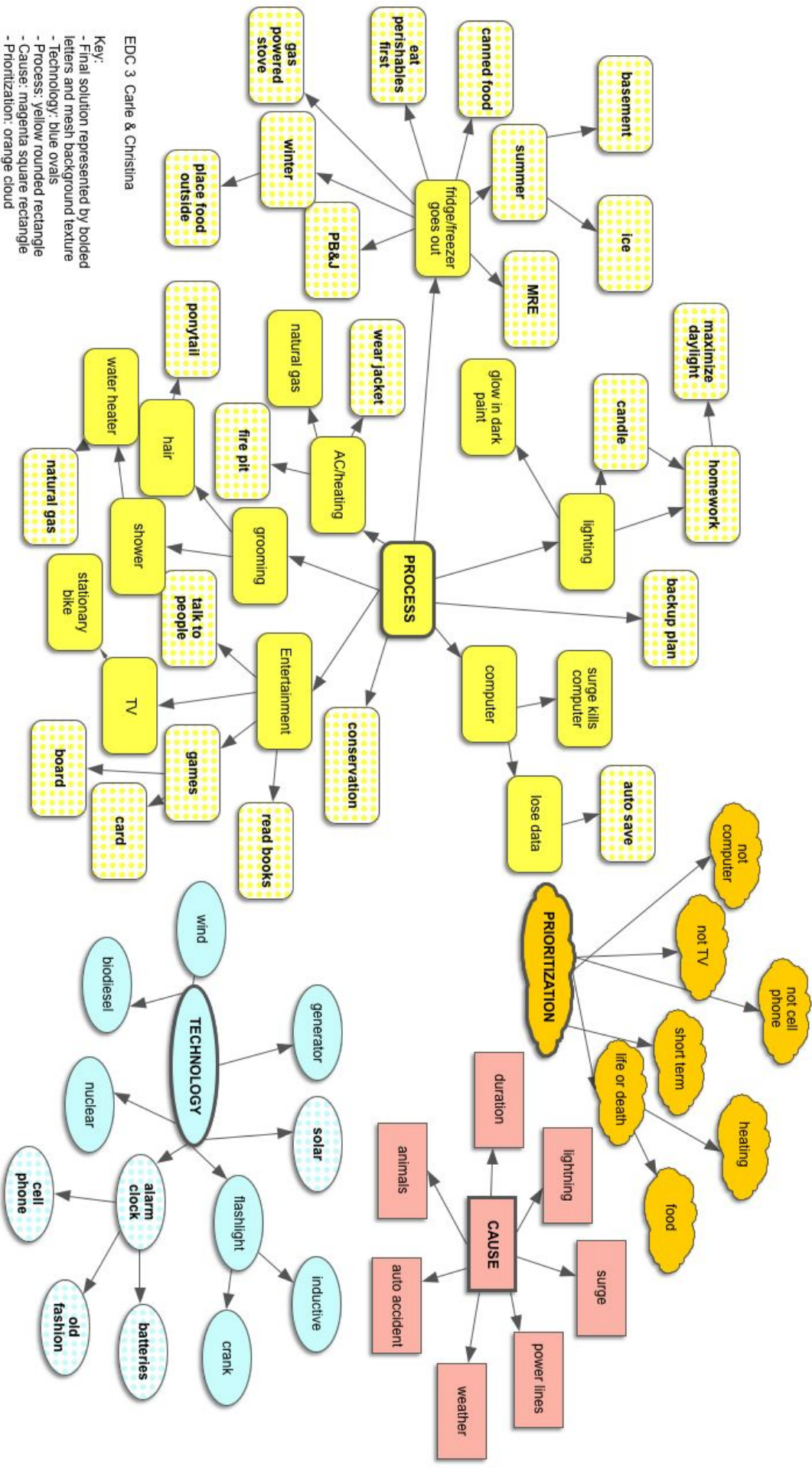






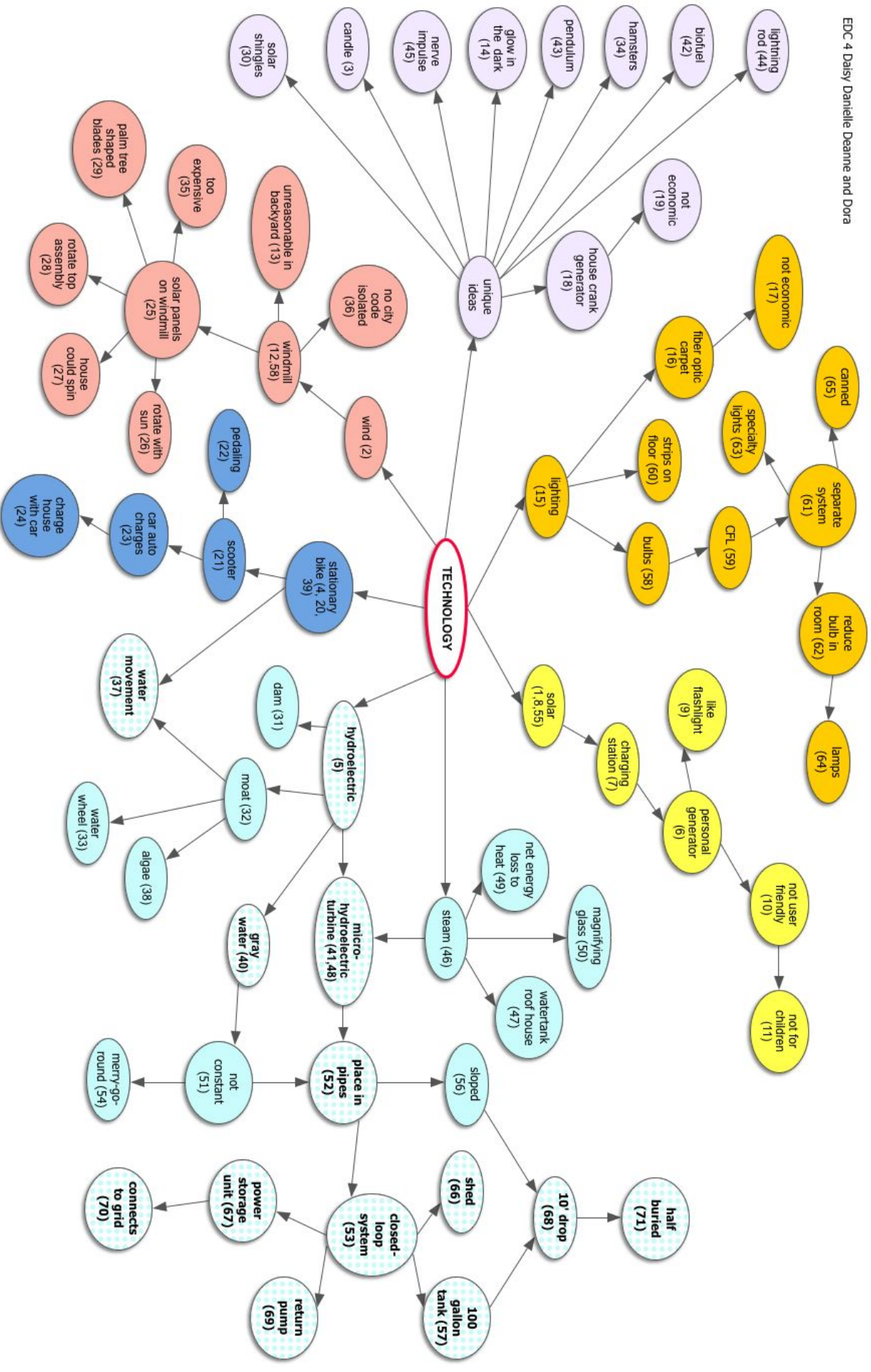
EDC 2 Bobby & Brian

- Key:
- Final solution represented by bolded letters and mesh background texture
  - Technology: blue ovals
  - Process: yellow rounded rectangle
  - Cause: magenta square rectangle
  - Prioritization: orange cloud



EDC 3 Carle & Christina

EDC 4 Daisy Danielle Deanne and Dora



## Conclusions

The student designers engaged in certain aspects of engineering design. They struggled with the open-ended problem and how to formulate it. However, the student designers were able to go back and formulate the problem iteratively in their design. From the reflective interviews, the student designers did not feel that they had adequate training or skills to attempt a design problem based in electrical theory. This study does not explain how much engineering content the student designers would require before attempting a design challenge with novel material.

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