Understanding "Failure" is an Option

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Additional projects involvement include: Engineering is Elementary (EiE) Project; Computational Thinking/Pedagogy Project; Rocket Project of SystemsGo; World MOON Project; East Lubbock Promise Neighborhood (ELPN) Project; and Robotics. Since 2013 he has served as the president of the Nu Sigma chapter of Kappa Delta Pi: International Honor Society in Education and was the founding president of ASEE Student Chapter at Texas Tech University. He can be reached at ibrahim.yeter@ttu.edu.

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"If you want to build a ship, don't drum up the men to gather wood or divide the work and give orders. Instead, teach them to yearn for the vast and endless sea." –Antoine de Saint Exupéry

Introduction

In 2005, the National Academy of Science, the National Academy of Engineering, and the Institute of Medicine published the report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*.[19] The report criticizes the loss of U.S. advantages in the marketplace in science and technology. They called for coordinated efforts to restore U.S. pre-eminence in science technology engineering mathematics (STEM) inventions, businesses, and work. The scientists, businessmen, educators and policy-makers that made up the committee that produced the report were responding to what they considered were abysmal performances by American students on international comparisons. Results from the Trends International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) found American students behind other industrialized nations.[20, 22] Additionally, demographics complicate matters.[3] After examining three large scale National Center for Educational Statistics (NCES) national data sets, Chen (2009) found that STEM majors tend to be male, younger, and dependent.[8] Additionally, Asian/Pacific Islander (who spoke a language other than English as a child) and students with more advantaged family backgrounds and strong academic performance dominate STEM majors at postsecondary institutions.[24] However, for a nation that is soon to become a majority minority (Craig & Richeson, 2014), this profile of STEM majors means that African American and Latinos are being left out of high paying STEM jobs, which are set to dominate the future.[9] Women are also less represented in engineering related fields.[16] Clearly, the education that young people received and their perception of said education are important in a young person's readiness and choice of a career.[5, 6]

When comparing U.S. STEM education to one country—Finland—one thing became clear from an American Society for Engineering Report (ASEE), "it's all about teachers (Wu 2011).[25] In this country that is outpacing much of the world in STEM education, teachers use a learn by doing approach to education, with learning from mistakes and trying again being an important part of the curriculum (according to Wu).[11, 25] In one critique of American education, schools focus too much on memorizing and not enough on problem solving (Svitak, 2014).[12] The effect is destroying interest in STEM early. The *Gathering Above the Rising Storm* report seemed to agree with this assessment because its first recommendation was to increase the U.S. STEM talent pool by vastly improving the k-12 STEM curriculum.[16] This includes an inquiry-based student-centered curriculum that includes meaningful hands on activities. Svitak (2014) also reported that peer-to-peer learning, early exposure to science research projects, and valuing failure as a key learning tool are essential keys to improving STEM education.[11]

The purpose of this study is to examine the impact of a technology-based project that uses the phrase "Failure is an option" as its motto. "Failure is an option" was said by William Broyles Jr. (one of the writers of the screenplay for Apollo 13) after he asked the flight dynamics officer Jerry Bostick, "Weren't there times when everybody, or at least a few people, just panicked?" Jerry Bostick's answer was, "No, when bad things happened, we just calmly laid out all the options, and failure was not one of them. We never panicked, and we never gave up on finding a solution." William Broyles Jr. left the meeting and came up with the phrase "failure is not an option" to exemplify the fortitude of the entire mission control team at NASA in Houston, Texas during the Apollo 13 Mission. The phrase was put into the movie and the rest is history (Houston & Heflin, 2015).[14] Despite this statement, inherent within the phrase, also came a blatant disregard for how "failure" differed across contexts and how "failing" can be seen as a product of the individual or the environment. Traditional teacher-centered learning in the classroom and student-centered project-based teams became two very different ways to approach a "failure." Failing a multiple choice test on obscure physics word problems is much different from having an aspect of a rocket project fail. Thus, it is our intent to discuss how students perceive "failure" in a student-centered, project-based learning environment.

For our purposes, we called this program the Rocket Project. In dramatic fashion, this program appears to meet the criteria being called for by those critiquing American STEM education. For the past eleven years a rocket program in Texas has been improving students' STEM knowledge, skills, and dispositions by having to build rockets and fire them into the atmosphere. The program started when the program director thought there was a better way of educating and motivating students about STEM. Not only do students learn technology, physics, and mathematics concepts, they learn powerful crosscutting skills and values, including, teamwork, leadership, communication, project management, and problem-solving. The curriculum framework is the systems engineering design process. This process has students defining problems, doing background research, developing possible solutions, making sure requirements are clear, building and testing prototypes, redesigning with more testing, then determining whether a solution works, and finally communicating the results. The culminating event is the launching of rockets. Student goals here include carrying payload from a mile high to 100,000 feet and parachuting the payload back to earth. Often, students get to present and discuss what they learned from data they gathered and from the experience with panels of engineers.

Research Questions. The researchers in this study used qualitative approaches to understanding the experiences of students and teachers in the program. The starting research questions are as follows.

1. What Rocket Project program experiences do students identify as key to their learning?
2. Once experienced, how can these learning experiences be defined?
3. In terms of learning, what do students see as the Rocket Project's strengths and weaknesses?

Review of the Literature

The theoretical framework for this study is informed by Ajzen's theory of planned behavior (TPB).[1] This theory argues behavior, such as entering a STEM career, can be explained by a person's intentions to engage in the behavior. The predictors of a behavior are an evaluation of the behavior, perceived social pressure to perform the behavior, and self-efficacy in relation to the behavior, also known in TPB as behavioral control (Ajzen, 1991).[1] In other words, a person's personal attitudes about a behavior, what one's friends, loved ones, and authority figures think about a behavior, and what one thinks about the ability to control an outcome will predict what people will do and how they perform. As for self-efficacy, TPB also considers external resources, like having the time and money needed for a person to successfully perform the behavior (Ajzen, 1991).[1] Attitudes toward the behavior, subjective norms, and the perception of behavioral control lead to the formation of a behavioral intention. Favorable attitudes and subjective norms, along with greater perceived behavioral control over the behavior, all increase the chances that people will carry out a behavior. For example, TPB would suggest that the combination of beliefs and attitudes from a student's home and school experience, along with a strong sense that one can control career choices should predict STEM major and career choice. In a large meta-analysis of wide ranging studies framed by TPB, Armitage (2001) showed that the theory of planned behavior accounted for significant proportions of variance in students' academic achievement in science.[2] Furthermore, students' personal experiences and their attitudes toward science were moderated by intention-academic achievement relationship. Our conclusion from TPB is that it is critical for educators to appreciate the factors that contribute to the cognitive and affective factors to promote sustained motivation. It is with this motivation that students will be more likely to reflect on their decisions within the group and persist through difficulties as they arise in STEM environments. Of course, motivation is one of the central features relating to reaching learning outcomes.

This study was also informed by the Social Cognitive Career Theory (SCCT) (Lent, 2005).[17] SCCT's roots can be found in Bandura's (1986) Social Cognitive Theory.[4] This theory suggests that models are key to knowledge acquisition and subsequent behaviors of those observing the model. Within this framework, SCCT argues that cognitive-person variables (self-efficacy, outcome expectations, personal goals) allow people to exercise personal agency when it comes to career choice. A person's agency is defined by that person's awareness of controlling aspects of his/her environment. Additionally, both environment (and other contextual variables) and past behaviors play a role in understanding career choice (Lent, Brown, Hackett, 2000).[18] Before enrolling in STEM fields of study, a number of contextual influences may come into play in terms of which major areas of study students actually choose. Within the SCCT and the TPB frameworks, these factors (e.g., teacher and parental support) may become contextual supports that facilitate students in choosing certain fields of study or circumstantial barriers (e.g., low socioeconomic status and poverty) that pull away from science and mathematics (Wang, 2013).[24] For instance, person inputs including several demographic variables (e.g., gender, ethnicity, and socioeconomic status) are the most inquired variables that are likely to affect one's interest and choice of the STEM field. Specifically, in STEM fields it is observed that males, Asian or Asian Americans, white students, and students from favorable socioeconomic background are overrepresented (e.g., Heinze & Hu, 2009).[13] However, research findings are not conclusive in the sense that after controlling for other influential factors, demographic differences tend to be attenuated. Moreover, willingness to complete the survey may have overrepresentation in certain groups and not in others (Porter & Umbach, 2006).[19]

Methodology

Methods and Procedures. In 2014 and 2015 approximately 500 high school students participated in a rocket program at their local Texas high schools in each of these years. Students taking these classes get high school credit for the classes. These were primarily juniors from 50 rural, suburban, and urban schools. Students can volunteer, but the notability of the program has garnered interest from many high schools and many students. First year students gain hands on experience by developing unmanned, remote-controlled aerial vehicles. Second year students launch rockets. Both years receive lab-based or elective science credit through Texas Education Agency's engineering pathway. In May of each of these years, students gathered in two cities across Texas to launch the rockets (the culminating event of their efforts). The data for this study were drawn from an end-of-year evaluation of the rocket program generated by these students. The open-ended questions were presented to students in an online survey format. Students were encouraged to tell stories about their experience. There were over 900 responses to the end of year questionnaire with over 650 responding to the open-ended responses. Here we focus only on the combined responses from two years of data about the students. Student responses were completely voluntary, and they could stop answering the questionnaire at any time. The students responded to two questions:

- 2014: Think about your experience with your rocket program, what / activities, lessons, or moments made the learning very effective? / Explain why.
- 2015: Tell us more about your experience. What did you like best about your rocket program experience?

There were other questions, but this analysis focused on these two because they best fit the research questions for this study. It is important to note that on many close ended questions that asked students to rate their experience on a 100-pt scale, upwards to 45% of the students chose 100 as the rating for their rocket project experience.

Coding of text responses. Students were encouraged to tell stories of their experiences. Initially, the data were coded using inductive qualitative procedures suggested by Creswell (2015).[10] In these procedures it is best to skim the data for a sense of tone and depth of responses. After doing so, start to group the responses into categories and then into themes. Two different coders independently coded the data for purposes of evaluation. The focus of the analysis was the textual analysis of students' open-ended responses. First, the text data were skimmed for a sense of the whole. Next, the researchers identified text segments for coding and labeling. Through a constant comparative coding procedure, the codes were reduced to themes and categories. The presence of a theme was verified by the frequency of its occurrence. The single coder then examined the themes for general conclusions. Using these impressions and themes as starting map, two other coders examined a sample of the data in order to establish interrater reliability and to describe themes from different perspectives, including looking for intensity and contrary evidence in major and subthemes. Finally, the researchers formed unified impressions of the emergent themes as contextualized by reviewing archived past reports of program performance and interviews with teachers.

For this research study, the combined year's data were analyzed and aided by software called Qualrus (v.2.1) that purports to use artificial intelligence in the textual analysis to support the code selection process. As one codes using this product, the coder can link concepts together and generate a graphical depiction of the relationship among the codes. When analyzing the data, it allows one to bring together all instances of a topic and present them in an organized fashion. This makes looking for patterns in the data much easier than coding by hand. In both coding cases (the independent coders and the coder using Qualrus), the analysis method that was used was constant comparative (where newly collected data is compared with new data). In this case, the new data are participants' responses that appear in a sequential order. The logic used is that of open coding, where patterns in codes result in categories, then themes. The recursive nature of coming up with codes and thinking about the patterns amidst the program context provided confidence that the themes that were identified captured what students were telling us about the program. 4 different coders performed multiple iterations of coding by hand and with software to visualize how themes converged.

Results

Prior to the formal Qualrus aided analysis, the researchers speculated that students' evaluation of their experience would center around two constructs—*discovery learning* and *fun* (See Appendix A for codes related to discovery learning and fun). These were key features of the experiences; however, they were not the central features of the experience that drove the program. While 16 codes were produced that represented students' opinions about the program, three stood out well enough to be considered the main categories from the responses. These categories are collaboration, teacher as guide, and positive failure. Figures 1, 2 and 3 show the codes related to these categories.

The students repeatedly indicated that collaboration was the key feature of their experience in their rocket programs. For example, one student described the experience in this way: "When we were all trying to build the rocket, we worked together and helped each other solve problems. We got things done more efficiently when we worked together, . . ." Another student stated that "we learned teamwork and we are going to use that for the rest of our lives." Yet another student participant said that, "learning was most effective when all viewpoints were shared and understood." The chief activity related to collaboration was working with the teacher as a guide, as noted in Table 1. One student described the relationship between collaboration and teacher as a guide in this way:

"Our teacher left the class to figure out most of the things needed to make our rocket go supersonic and even though we failed now we know why we failed because we had to create the rocket by what we thought would make it go supersonic. The fact that we had to figure almost everything out by ourselves made all of these lessons stick better."

Other activities related to the collaboration include peer-to-peer work, discussions, and multiple points of view. Attitudinally, students felt that collaboration helped them mature and visualize solutions to problems.

The teacher as guide category appeared to be the central causal agent for students seeing the experience as challenging, for collaboration, discovery learning, discussions, maturity and time pressure. One student described the intersection as shifting the center of learning from the teacher to the team. However, the teacher is never far away:

"Learning how to use the computer program to design your own rocket helped me to be successful and learn something I had no idea about before this year. I liked the way that our teacher would interact with us and help us with what we needed and when we would get stuck. The most important part I learned was working as a team and not having the teacher do the whole rocket for us. Therefore, letting us learn more effectively. Our instructor would not tell us exactly what we had to do, but would guide us to figure it out for ourselves. Building the rocket really taught me how to put a big project together by my teacher describing all the parts needed in order to fly a rocket I think that the most effective part of the learning process was the fact that I was forced to overcome my issues on my own."

The final key aspect of students' experience was learning from failure. The identified codes indicated that students took on the notion of learning from failure with nearly universal positive statements. In fact, the motto of the program is "failure is an option." It was clear that students bought into and learned from what the researchers are calling *positive failure*. In a comment that captured many aspects, influences, and results of positive failure, one student captured the multilayer nature of the experience:

"My rocketry team had worked hard on the rocket, and when it came to competition, it was successful when our rocket came off the payload. I think it is just fun to build and watch what happens. I think the most helpful things that made our learning effective were not lessons or assignments. When it came to these rockets, the most efficient things we learned were gained from our own failure and experience. There really was no way to prepare us for some of the things that happened once we got to the site, and it was up to us to learn quickly in order to stay on schedule."

Table 1. Coding of Text Segments			
Ranking of frequency of major code occurrences			
Individual Codes		Code Pairs (Co-occurrences)	
Collaboration	48	Collaboration::Teacher as guide	7
Teacher as guide	30	Positive failure::Collaboration	6
Positive Failure (learning from failure)	20	Collaboration::Problem solving	5
Problem solving	16	Teacher as guide::Independence	4
Using unique tools	16	Positive failure::Teacher as guide	4
Inspiration	15	Independence::Inspiration	3
Independence	13	Collaboration::Research	3
Hands on learning	10	Unique tools::Collaboration	3
Fun	9	Inspiration::Confidence, Launch event:: Inspiration, Fun:: Inspiration, Fun::Challenge, Independence::Hands on, Problem solving::Research, Problem solving::Simple to complex, Teacher as guide::Fun, Collaboration::Inspiration/Challenge/Fun /Independence, Positive failure::Challenge/Fun, Unique Tools::Inspiration, Unique Tools::Teacher as guide, Active learning::Collaboration	=2
Active learning	9		
Research, learning from simple to complex, challenge, discovery learning, planning, the launch event, confidence, goal attainment, logical analysis, eye opening, peer-to-peer learning, time pressure, experimentation, maturity, making connections, grit, motivation	<9		

Table 1 represents the codes and themes discovered with Qualrus v.2.1 software (Brent, Slusarz, & Thompson, 2002).[5] The two columns represent the frequency of code occurrences. The first column illuminates the 3 major individual themes that emerged based on the frequency of its occurrence in responses: *Collaboration*, *Teacher as Guide* and *Positive Failure*. Other notable themes that emerged were problem solving, using unique tools, inspiration, independence, hands-on learning, fun, active learning, research, learning from simple to complex, challenge, discovery learning, planning, the launch event, confidence, goal attainment, logical analysis, eye-opening, peer-to-peer learning, time pressure, experimentation, maturity, making connections, grit and motivation. There were also co-occurrences where themes and codes were used in tandem. This is shown in column 2, labeled "Code pairs (Co-occurrences)." The top three code pairs were collaboration with teacher as guide, positive failure via collaboration and problem solving via collaboration. Other notable code pairs were Independence with teacher as guide, positive failure with teacher as guide, independence and inspiration, collaboration and research and collaboration using unique tools.

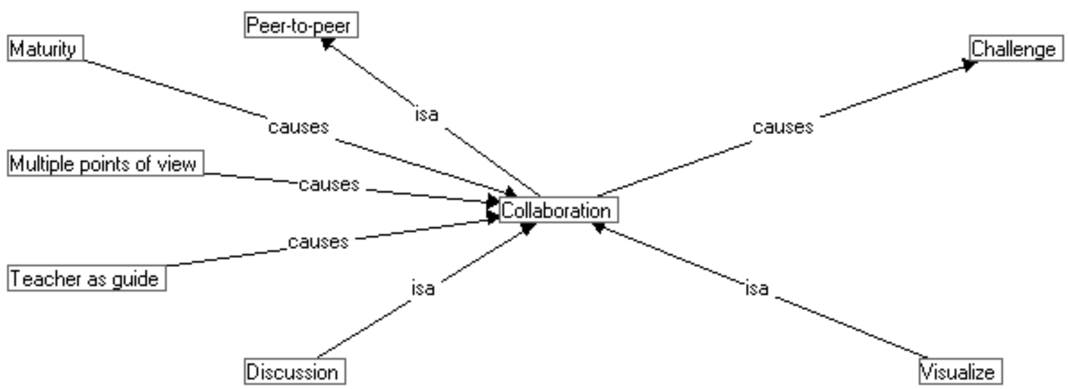

Figure 1. Codes related to collaboration

The "causes" and "isa" designations for all figures are based on links or relationships among codes within the Qualrus software package. Codes can be linked together to form complex relationships. The "isa" designation represents hierarchies in which some codes are subsets of other codes. The "causes" link is also a standard in the Qualrus software that searches for links and relationships between codes and the arrows define the direction of the relationship (Brent, Slusarz, & Thompson, 2002).[5] Thus, discussion and being able to visualize are subsets of collaboration in general. Collaboration can lead to peer-to-peer interactions and challenges. Similarly, maturity, multiple points of view, and a teacher as a guide all contribute to collaboration.

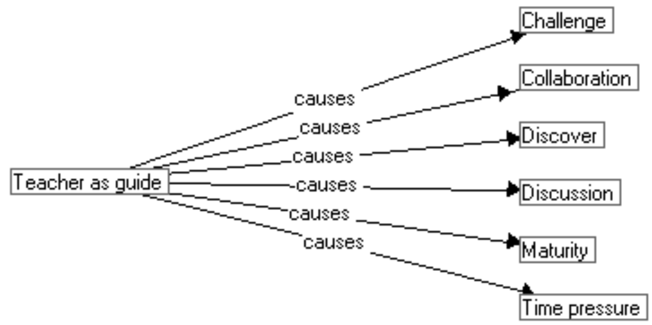

Figure 2. Codes related to Teacher as Guide

In Figure 2, the *Teacher as a guide* causes a challenge, which in turn spurs collaboration, discovery, discussion, maturity and time pressure. Thus, according to these codes from student responses, the teacher forms a fundamental baseline for aspects of learning in problem-based environments.

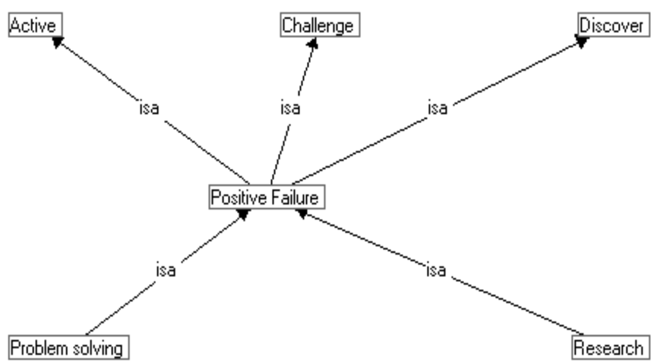

Figure 3. Codes related to Positive Failure

Figure 3 represents *Positive failure* as a product of problem solving and research according to student responses. *Positive failure* can also contribute to active learning, discovery and other challenges.

With these findings in mind, we believe that the model in Figure 4 emerged from the textual data. Here, the top circle is the engine of all student activities related to learning from building rockets. It also appears to be the driver of student attitudes about learning, particularly when students describe their collaborative activities leading to learning independence. Second, the attitudinal mindset of the groups was learning from failure. When a student occasionally revealed what they needed to overcome the "failures," the answer was often more data and research. These failures were related to testing aspects of the rocket that one finds in the engineering design process, rather than failures of will or character. Other failures mentioned were related to breakdowns in how the teams worked; however, for the most part the teams provided the self-correcting power to overcome technical problems, like miscalculating fuel ratios, or soft skills problems, like not communicating well to teammates. Finally, if collaboration is the engine, the teachers' ability to manage teamwork and motivate students through failures was the lubricant. Generally, students were very positive about their teachers. One student said this about his teacher as a guide: "Encouragement from my instructor to figure things out myself has been very beneficial to my learning experience." Another student summed up the experience for many like this: "My teacher's attitude about stepping out of the way and letting all of us students do all of the research and work was a very effective teaching strategy, because it really made us students learn how to think and problem solve effectively."

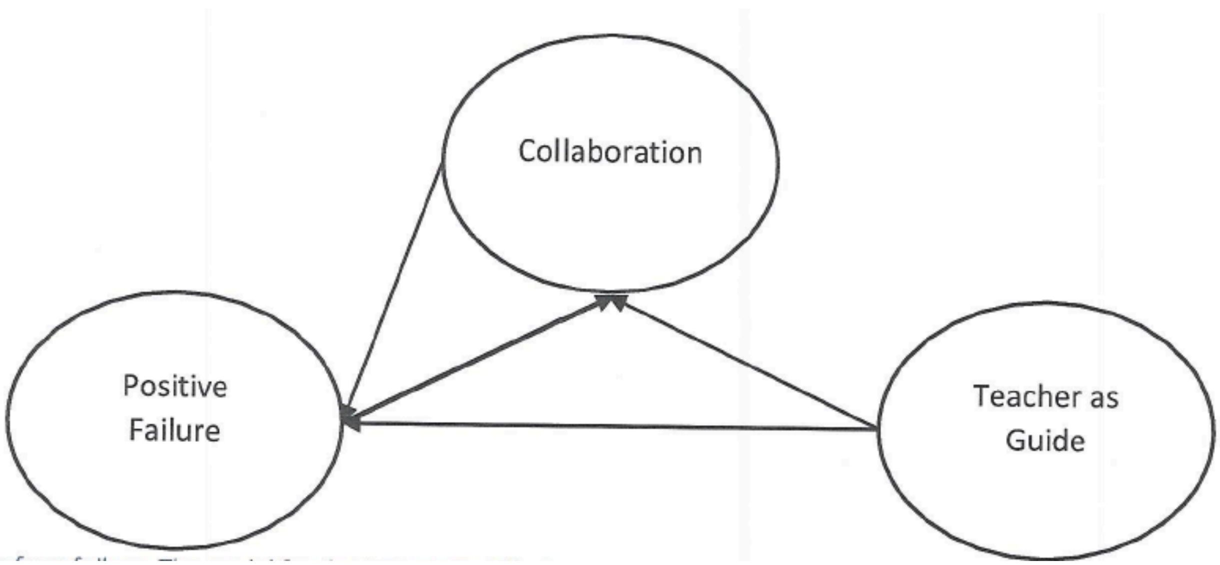

Figure 4. Learning from Failure: The Rocket Program Effect

Conclusion

With the above findings in mind, we describe the theory that explains these students' experiences with the rocket program curriculum as the Rocket Program Effect. The students in the program would agree with Svitak's conclusions about STEM education: Failure is life's built-in educator.[23] After coding qualitative responses and searching for themes using the Qualrus software program, it seems that students not only understood what "failure" meant in the context of the aerospace environment, but they also enjoyed failing with their team members. This enjoyment of "failure" was frequently cited by students as being extremely important to them. One possible reason is that collaboration with group members and hands-off teacher scaffolding provided the basis for a positive outlook on failure. The students appear to be motivated by the spirit of the program, as represented by the dynamic interactions among teachers, peers, and even practicing engineers. This motivation is central to students using learning strategies and social relationships to keep trying to find solutions, even when things do not go as expected, repeatedly. This attitude of curiosity is enhanced by what Ajzen (1991) calls subjective norms.[1] These attitudinal and belief norms are perceived to be set by significant others, like teachers and peers. The teachers keep students focused on finding solutions based on data gathered from mistakes. In a traditional school setting, a mistake is to be avoided, rather than embraced. While in their teams, peers help reinforce this attitude (even cultural value) by mimicking the teacher's attitude toward failure. Similarly, the students appear to be taking on the attitude of researchers: professional, independent, and interdependent. The students seem unafraid of and even hungry for cognitive dissonance produced by the teacher's role, which can seem distant to those students familiar with only a teacher-centered classroom. One student described the experience like this: "Our teacher helped us find solutions to our own problems without giving us direct answers. This taught me to be creative, and put [in] effort until I can find a solution. It made me better at independent thinking."

Added to a teacher's guiding students through failure is the power of collaboration. When collaborating as a team, overcoming "failures" as a positive behavior get routinely enhanced and emphasized. Principles learned from engineering education may be the antidote to state and local curricula poisoned by heavy standardized testing. Quite possibly, the principles inherent within this rocket program could be generalized to humanities, social sciences and other career and technical fields. The program itself continues to increase interest in STEM fields in Texas. Many of the students go on to work at high paying aerospace engineering jobs and expansion of the program is dependent on corporate donors, as well as, student participation. It is our opinion that the blossoming aerospace engineering industry will need many more competent aerospace engineers with hands-on experience, the ability to collaborate with others, meet deadlines and see problems as opportunities. For these brave students, the sky may simply be a transition, not the limit.

Notes

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Appendix A: Expected Relationships among Codes.

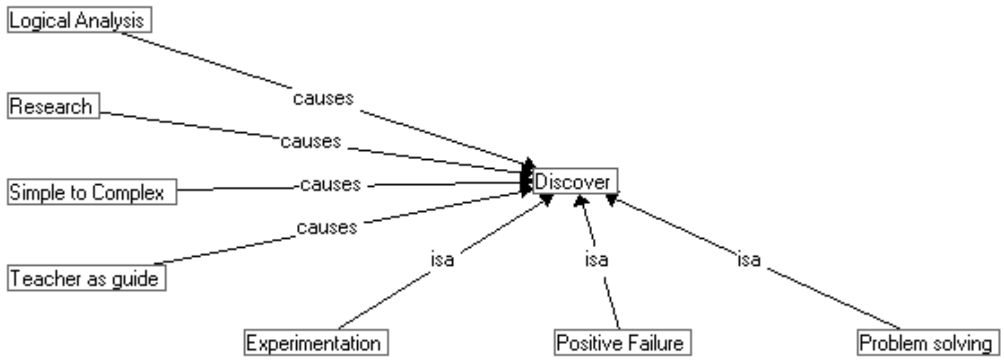

Figure 5. Discovery learning hypothesized at the center of the experience

Figure 5 shows us that *Discovery* is caused by logically analyzing problems, research, simple to complex problems and having the *Teacher as a guide*. It also shows us that Discovery is a product of experimentation, *Positive Failure* and problem solving.

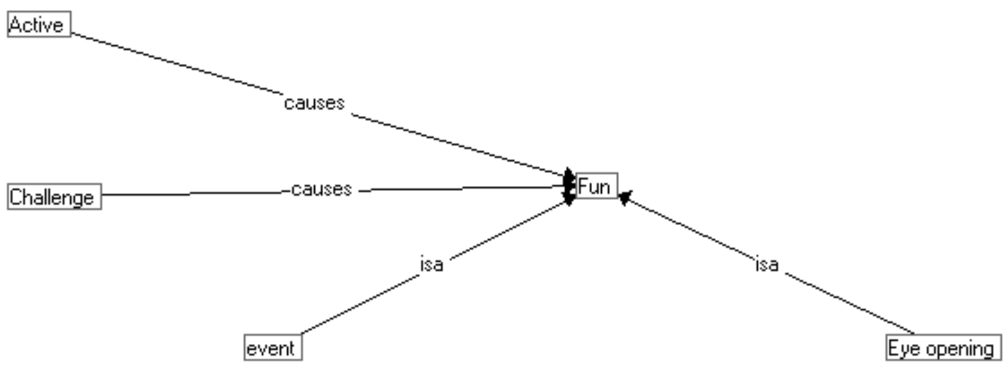

Figure 6. Fun hypothesized at the center of the learning experience.

Figure 6 displays the codes for Active learning and challenges as they may be influencing fun. Fun can also be the product of eye opening events in the environment.