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Abstract

Teachers need to develop a variety of pedagogical strategies that can encourage precise and accurate communication - an extremely important 21st century skill. Precision with STEM oral language is essential. Emphasizing oral communication with precise language in combination with increased spatial skills with modeling can improve the chances of success in STEM courses and later in making STEM career choices. The participants were 14 middle and high school teachers who participated in a week of professional development (PD). The Aural/Spatial Interactions and Invariant Components of Vocabulary for STEM Content Area Specialists (AS-STEM) was administered to teacher groups to examine how STEM discourses influenced AS-STEM success. This study compared language differences among groups that were more versus less successful at representing unseen 3-D objects by drawing 2-D depictions from oral descriptions from peers. The groups that were more successful, able to produce more accurate depictions, used (a) language type merging that was more coherent and less frequent, (b) language precision that appeared to convey meaning effectively, and (c) validated shared meaning regularly and established these shared meanings efficiently. Thus, teachers who were able to merge language types using precision and jointly took ownership of the tasks were more successful. We trust that this work translates into practice through the awareness teachers had from participation in and discussion of the activities.

Introduction

Communication is an important 21st century skill. Oral communication is necessary in order for people to share knowledge, describe things, encourage others, and justify and reason. Some people outshine others in casual friendly conversations but are challenged when they are in academic situations (Owens, 2015). Interactive teamwork skills are usually depicted as exclusive from science and mathematics skills, suggesting that people are generally more competent in one at the expense of the other (Correll, 2001). The stereotype of engineers as solitary individuals exists when in reality 21st century engineers and scientists "must be team members who thrive while working with a variety of people having differing social, educational, and technical skills" (Seat, Parsons, & Poppen, 2001). This active and appealing setting is attractive to students, particularly girls (Correll, 2001). Thus STEM (Science, Technology, Engineering, and Mathematics) teachers need to encourage these cooperative communication activities in their classrooms.

There are a variety of pedagogical strategies teachers can use to emphasize the necessity for communication in STEM subjects (Moschkovich, 2010). Integrating speaking and writing assignments within the framework of a mathematics or science lesson emphasizes the importance that language and communication play as an indispensable part in the hard sciences (Bicer, Capraro, & Capraro, 2013; Bicer, Capraro, & Capraro, 2014; Hill, Charalambos, Lewis, & Ball, 2008). When students were provided ample opportunities to use the language of mathematics, their mathematical vocabulary understanding increased (Kranda, 2008). When introducing a STEM topic, teachers need to include oral presentation rubrics with particular importance placed on precise communication (Scutt, 2014).

Precise Communication

On the old engineering/computer science building of Michigan State University, the following words can be found, "The English language is your most important tool, learn to use it with precision." Precision is a relative theory that pertains to communication, measurement, and computation. Communication is more precise if it has little risk of being misinterpreted. Computation and measurements are more precise if they contain a greater amount of exactness (Otten, Engledowl, & Spain, 2015). Formal mathematical language greatly increased preciseness of communicating mathematically (Azzouni, 2009). Precision is extremely important when working with representations, computations, and measurement.

A part of precision in mathematics is being correct or accurate. Thus, when students make few errors, they are precise (Otten, Engledowl, & Spain, 2014). Another part of mathematical precision is defining things explicitly and being careful when discussing specific measurement units (National Governors Association Center for Best Practices, & Council of Chief State School Officers, 2010). Otten et al. (2015) examined the preciseness of high school mathematics teachers in univocal or dialogic discourses and found limited examples of discourse between teachers and students. However, few studies have examined preciseness of communication when describing two and three-dimensional objects as a part of spatial visualization tasks.

Spatial Visualization Skills

Cultivating spatial skills improves the retention of all engineering majors thus helping to reduce the gender gap in STEM areas (Assessing Women in Engineering [AWE] Project, 2005). Spatial skills are important in engineering for picturing and drawing two and three-dimensional sections and structures in order to construct prototypes. The ubiquitous stereotype of females possessing limited spatial skills has contributed to the gender disparities in STEM fields. Scientific research does not support genetic disparities as the source of gender variances in spatial skills (AWE Project, 2005). Research (Assessing Women in Engineering Project [AWE], 2005; Branoff & Connolly, 1999; Ferguson, Ball, McDaniel, & Anderson, 2008; Peters, Chisholm & Laeng, 2013; Seabra & Santos, 2008) exists demonstrating a relationship between engineering successes and spatial skills abilities. Sorby (2007) demonstrated that spatial visualization skills were a strong predictor of these successes. A longitudinal study found that first-year women engineering students with inadequately developed spatial skills who are involved in intense spatial visualization activities were prone to remain in engineering rather than other students who do not engage in these types of spatial activities (Sorby, 2007) There was not any statistical difference for males indicating that a spatial-visualization intervention produced an effect by gender for retaining students in an engineering degree program (Sorby, 2007). Regardless of age or gender, Safhalter, Bakracevic Vukman, and Glodes (2015) found that 3-D modeling improved middle school students' spatial visualization skills.

The National Council of Teachers of Mathematics (NCTM, 2000) has recognized the importance of well-developed spatial skills for careers, thus including standards for developing spatial abilities. For middle school mathematics education, there has been a national interest in spatial visualization as results from the Third International Mathematics and Science Study were examined (Belal & Arsaythamby, 2015). Although students differ in their spatial skills, research has revealed that many component skills of visualization can be developed through coaching and practice. Regardless of gender differences in spatial abilities and research demonstrating the malleability of these skills in a short period of time (Hsi, Linn, & Bell, 1997), the effect of spatial skills interventions seems encouraging in narrowing the gender gap for engineering degrees.

Theoretical Framework

Emphasis on precise language in oral communication in combination with increased spatial skills can improve the likelihood of success in STEM courses and career choices (Bicer, Boedeker, Capraro, & Capraro, 2015). Our theoretical framework is depicted below in Figure 1. In our previous work (Barroso et al., In Press 2016), a flowchart depicted the flow of language within the study. During the cognitive labs, teachers' communication flowed among analogous, technical, and clarifying languages.

In this study, we further examined the drawings of those groups who were more successful as compared to those who were less successful. We then attempted to compare the discourse patterns that emerged from both the more successful and least successful groups in the areas of sense making capacity and without sense making capacity to explicate patterns leading to successful discourse as measured by drawers' producing reasonable two-dimensional drawings of unseen three-dimensional objects that were verbally described by others during cognitive labs.

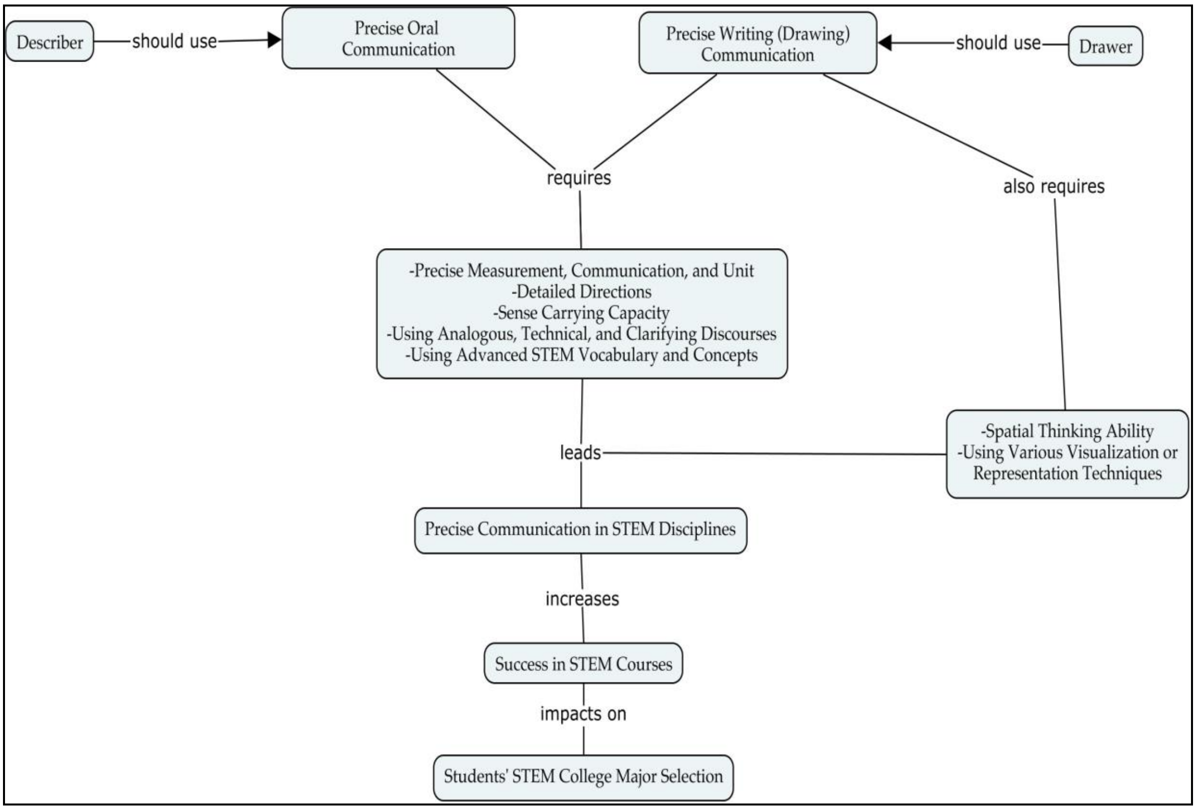

Figure 1. Theoretical framework for present study

Participants

The participants were middle and high school teachers who participated in a summer residential, week-long professional development (PD) during July of 2015. The PD was held on a large public university campus in the southwest and included sessions on 3-D printing and STEM project-based learning (Capraro, Capraro, & Morgan, 2013). For this study, we examined the discourse language of 14 teachers (10 females; 6 White; 3 African American; 2 Hispanic; 1 Mixed; 2 Asian Americans) as they described a 3-D spatial object Teachers included: mathematics (5), science (4), engineering (2), language arts (2), and social studies (1). The teachers all had over two years of teaching experience with most of the rest of them having over five years and up to 25 years of experience in the classroom.

Instrument

The Aural/Spatial Interactions and Invariant Components of Vocabulary for STEM Content Area Specialists (AS-STEM) Instrument was created to measure how teachers used content specific discourse after a STEM PD and to compare STEM discourses. In this study, the AS-STEM was administered to examine how groups of teachers used STEM discourses and to compare the languages that emerged from groups of teachers who were successful at drawing the 3-D object in contrast to those who had difficulties drawing the 3-D objects. The task required teachers to describe a 3-D object to other teachers who drew views of 2-D models of the object without being able to see the object thus using only verbal descriptions.

A cognitive lab was the setting for the administration of the instrument. Drawers and describers were divided by a large cardboard trifold that prevented drawers from viewing the object and did not let the describer see what was being drawn. The conversational discourse between the describers and drawers was recorded digitally. Grid paper and rulers were provided to the drawers. A digital caliper and a uniquely shaped 3-D object were given to the describers. Examples of the two 3-D objects analyzed and discussed in this study are pictured in Figure 2. Each group of teachers heard the same directions at the beginning of the cognitive lab. The teachers were allocated 15 minutes. During this time, the describers used language only to convey details about the object to drawers.

The groups were allocated 15 minutes for the describers to collaboratively measure and describe the 3-D object to the drawers. Each drawer was expected to draw orthographic projections (i.e., 2-D views) of the described object. When the time was over, the participants changed roles and tools, the new describers were provided another object close to the same complexity, and they were provided 15 minutes to finish the task. The audio recordings from the group discourses were transcribed.

Figure 2. 3-D objects drawn

The research question that guided this study was: How does communication differ between groups who create more accurate representative depictions of a described three-dimensional object versus groups that do not as measured by the AS-STEM?

Qualitative Analysis

Following traditional case study analysis of our focused topic of STEM communications, we examined teachers in a summer STEM PD (Creswell, 2009). Teachers were placed in four groups as either describers or drawers. We examined the data corpus to find contrasting outcomes of groups drawing the same objects with differing outcomes. That is, we found four groups, two groups described/drew one object and the other two groups a different object. For each of the two objects and groups, one group created a better depiction of their object compared to the other group. We hypothesized that the language would vary among all groups; however, we wanted to determine how the language compared among the groups whose drawings were more accurate depictions of the 3-D objects versus the language of groups whose drawings were less accurate depictions or less complete. After the groups were selected, we analyzed the transcribed AS-STEM Cognitive Labs using iterative cycles of constant comparisons followed by interpretive analysis (Patton, 1990). To strengthen the reliability and validity of the analysis multiple members of the research team analyzed data and validated findings by examining the transcripts (Altheide & Johnson 1994).

The initial analysis of the transcripts focused on coding the types of language (e.g., analogous, metaphoric, and technical) were defined in a related study (Barroso et al., In Press). We were also interested in coding how interactions included merging language types and its precision (e.g., using accurate measurements with units and/or clarity of meaning). There were multiple coders who coded the transcripts iteratively, using a constant comparative process that revealed additional and unanticipated themes: communication positioning, validating shared meaning, and mathematics efficacy. Through the process, we developed a codebook with meanings defined over a continuum from more productive communication to less (see Table 1). The analysis culminated by taking a reflective look across all coded transcripts searching for insights about the two groups that produced better depictions of the original 3-D objects versus those that produced less representative drawings.

Table 1. Categorical themes defined over a continuum used for coding

	Thematic descriptions continuum	
Categories	**More productive communication ...**	**Less productive communication**
Communication positioning	Working collaboratively – pronouns and language are inclusive	Working individually – pronouns and language are exclusive
Language type	Using analogous, metaphoric, technical, scientific, or other types of language	Using analogous, metaphoric, technical, scientific, or other types of language
Language merging	Merging multiple language types in a coherent context	Merging language types but without a coherent context
Language precision	Using precise measurements and units and/or using language that articulates meaning clearly	Giving approximate or imprecise measurements and perhaps omitting units and/or using language that is less clear
Validating shared meaning	Explicitly checking, clarifying, questioning; shared meaning established before moving on	Explicitly checking, clarifying, questioning; shared meaning not established and/or repeated queries posed
Mathematics efficacy	Using mathematical terms and/or concepts confidently	Using mathematical terms tentatively

Results

The results of the analysis revealed several interesting things about the communication used by both sets of groups as can be seen by the drawings provided in the Appendix. First we will describe characteristics of communications among groups able to produce representative depictions of the 3-D objects. Then we describe communications among the groups that produced less representative depictions of the 3-D objects. Finally, we compare the communications between the successful groups and the less successful groups.

The groups that produced representative depictions of the 3-D objects used more productive communications: (a) language type merging was more coherent and less frequent, (b) the language precision appeared to convey meaning effectively, and (c) validating shared meaning occurred regularly and shared meanings were established efficiently. These communication characteristics appeared to support a more successful task outcome for these two specific groups. Conversely, the groups that were less able to produce representative depictions of the 3-D objects used less productive communications: a) language type mismatches occurred between describers and drawers, b) language type merging occurred frequently and was less coherent, and c) validating shared meaning failed to establish shared meaning, often after multiple attempts at validation. These communication characteristics appeared to support a less successful task outcome for these two specific groups.

To clarify the meanings provided for the thematic descriptions, we will provide examples from the groups. All groups used a variety of language types, but groups with less successful outcomes had more instances where their language types were mismatched between the describers and drawers. For example:

> Describer: . . . Ok, um, this is similar to a, uh, a stop sign missing one of its sides of that shape. Well, actually, two. Um… on a—
> Drawer: So a stop sign in the terms of hexagon?
> (Transcript #4)

In this example, the describer used metaphoric language, “similar to a, uh, a stop sign” and the drawer responded with scientific language, “in the terms of hexagon.” The group discourse continued with the describer using metaphoric and everyday language and the drawer rephrasing using scientific language, such as polygon names and characteristics like the number of sides. After which, the group appeared to attempt to validate shared meaning. However, because each group was using different language types, the attempts to establish shared meaning was often lost and the group decided to either move on or the attempt to validate shared meaning repeated.

An example of language type merging occurred in the previous example as the drawer translated the metaphoric language to the scientific language, but the describer did not take up the scientific language for further description of the 3-D object. However, a more productive communication example of language type merging occurred in a group with more successful outcome:

> Describer 1: Ok now you're going to turn right again. 90 degrees. Approximately 7 mm…
> Drawer 2: So the 7 mm is the rest of the outside of the hexagon…Is parallel to the base…Now you're at the top so…
> Describer 1: Ok so yeah the next line that you make will be parallel to the bottom, yeah. You got all fancy with the base.
> Drawer 2: Well I used to teach geometry so.
> (Transcript #6)

In this example, the describer uses everyday directional language, "turn right" with scientific language, "90 degrees;" and the drawer responds using scientific language, "the hexagon… Is parallel to the base" and everyday directional language, "at the top." The describer responds by acknowledging shared understanding and making note of their shared meaning for what the describer referred to as the "bottom" in the description and the drawer used mathematical vocabulary, "base." To which the drawer attributes to past geometry teaching experience. This exchange is also a brief example of validating shared meaning that is established efficiently.

Finally, *language precision* within the more productive communications manifested in two ways. An example of using precise language *f*rom a group that was less successful at depicting the drawing used productive communication, both flavors of *language precision* per our description (see Table 1):

> Describer: So you're going to have two disassociated lines on the paper [laughs]. That are right angles to each other and that line should be 30… I'm sorry. 31 mm.
> (Transcript #4)

One way that *language precision* is shown is using well-articulated language such as, "two disassociated lines . . ..That are right angles to each other" In this example, it appears that the describer realized that the initial description of the two lines was unclear and makes a clarification of the language to describe the two lines being described. The second type of language precision has to do with the way measurements are given, with precise numeric values and units "30… I'm sorry. 31 mm." In this case, it appears that the describer checked the measurement reading using the caliper and revised it.

To address the research question, comparisons were made to identify differences in communication between more successful versus less successful groups in creating representative depictions of described three-dimensional objects. There were several differences that were interpreted as contributing to more successful outcomes for groups, including a) no language type mismatches, b) language merging that maintained coherence, and c) efficiently validating shared meaning regularly. Both groups used multiple language types; however, the less productive groups had instances when the describers used one language type and the drawers used another. These language type mismatches were not found in the more successful groups' communication. Interestingly, both types of groups used language type merging, but a significant difference in the way that language type merging manifested had to do with coherence. That is, meaning was not lost but perhaps enhanced through language type merging, for example, consider:

> Drawer 2: So the tri…triangular popsicle stick is where? Is it depending on the stick?
> Describer 1: The stick is centered right in, centered on the, on that…um that base.
> Drawer 2: Ok.
> (Transcript #5)

The drawer asks a question using only metaphoric language, but the describer uses language type merging to add clarity for the drawer by initially using what appears to be shared metaphoric language, "The stick is centered" and merges that with scientific language, "that base." To which, the drawer appears to acknowledge affirmative understanding with an, "OK."

The way describers and drawers communicated with each other varied among the four groups. While the describers and drawers from the groups who produced representative depictions of the 3-D objects worked collaboratively and used inclusive language, the describers and drawers from the groups that produced unrepresentative depictions of the 3-D objects worked mostly individually and used inclusive language. We named this difference as communication positioning. For example, describers and drawers from the groups that were more successful preferred using "we" pronoun more often than "I" or "you" pronouns.

Describer 2: So, let's start with that, we are going to start with the length of the popsicle stick.
Drawer 1: Ahmm.
Describer 2: And it is, hang-on.
Describer 1: Twenty-three point four millimeters.
Describer 2: Did you hear her?
Drawer 1: Yup.
Describer 1: Diameter.
Drawer 1: Slow down, got to draw.
Describer 2: Gotcha.
Drawer 2: Twenty-three?
Describer 2: Twenty-three point four millimeters.
Drawer 2: I do not know if we are only going to get the top view, if we need to show that.
(Transcript #5)

However, describers and drawers from the group that was less successful preferred using "I" and "you" pronouns more often than "we".

Describer 1: What no, so if you measure, if you, arg I don't have a pencil. So if you measure straight down from the center from the point where the triangle will be.
Describer 2: Ah-huh.
Describer 1: To here and draw a line of one inch, a line across and there will be able create that curve. So I need to figure out what that distance is. If I had a pencil, I can trace a line across you know.
Describer 2: So…
Describer 1: Do you have a pencil with you?
Describer 2: No, I gave it to you.
Drawer 2: I think I have an extra one.
(Transcript #9)

Both groups used mathematical language to be able to produce representative depictions of 3-D objects. However, describers and drawers from the more successful drawing groups used mathematical language more efficiently than describers and drawers from less successful drawing groups. We labeled this as mathematical efficacy of groups that identified whether describers and drawers used numerous advance mathematical terms and concepts in a context when they were trying to describe geometrical identification of 3-D objects. For example, the more successful drawing groups used mathematical terms including but not limited to "radius", "circle", "diameter", and "center".

Describer 1: And kind of largely rounded. If you took a diameter of the circle, and this is just an estimate because I can't find the exact center point. It's like about ten millimeters approximately. So you are looking at about a centimeter radius on all the circles.
Drawer 1: Ok.
(Transcript #5)

However, describers and drawers from the group that was less successful did not efficiently using mathematical terms when it was necessary to describe the geometrical characteristics of the 3-D objects.

Describer 1: And you go back at and make a point, you know the 29mm.
Drawer 1: Right.
Describer 1: And turn and.
Drawer 1: Oh ok.
Describer 1: And turn back 30 degrees towards the, to meet up with the other lines. Does that make sense?
Drawer: Um, yes. But it is not working out. I am getting what you are saying but I am getting.
Drawer: I think maybe you and I had a disconnect a long time ago. (Transcript #4)

Finally, all groups spent a significant amount of time validating shared meaning. In fact, this category was the most frequently coded for all groups, which we interpreted as regularity. That is, all groups regularly checked for shared meaning, but the difference for the more successful groups was the efficiency in which validating shared meaning was established. Consider, the following example:

Drawer 2: All three corners of the triangles are rounded as well?
Describer 1: Yeah all of them are rounded.
Describer 2: All three are rounded.
Describer 1: And kind of largely rounded. If you took a diameter of the circle, and this is just an estimate because I can't find the exact center point. It's like about ten millimeters...approximately. So you are looking at about a centimeter radius on all the circles.
Drawer 1: Ok.
(Transcript #5)

In this example, all four group members participated in the communication. The problem was that the 3-D object had rounded corners and the describers' tools did not lend themselves to easily or exactly measure them. The describers appeared to work collaboratively to clearly articulate an approach to describe the rounded corners. The drawers appeared to be working collaboratively because drawer 2 asked the original question and drawer 1 acknowledged understanding. The drawers moved on to another aspect of the object with a new question from drawer 1. The rounded triangular corners were not brought up again within the communication, suggesting understanding.

In summary, the groups that communicated more productively as measured by the AS-STEM, their communications appeared to afford a "sense carrying capacity" that enabled them to represent a 3-D object from verbal description alone (Barroso et al., In Press). Conversely, the less successful groups' communication appeared to afford limited or no sense carrying capacity that hindered ability to successfully represent 3-D objects form descriptions alone.

Conclusions

Merging of language types, the ability to use language precisely and working collaboratively enabled teachers in our study to produce drawings that were more closely aligned to the 3-D object they were given. We found that teachers who truly worked collaboratively were more successful in their drawings. We also found that collaborative argumentation was associated with engagement (cf. Evagorou & Osborne, 2013). These collaborative students in the Evagorou and Osborne (2013) study, similar to the teachers in our study, who took ownership, asked clarifying questions, and jointly took ownership of the tasks were more successful. Teachers who used precise language were able to communicate more clearly with peers and drew more accurate models that represented the 3-D objects they were provided.

Translational research has the potential to be used across a broad spectrum of constituents (Wolf, 2008). Translational research might mean different things to different people, but regardless of its meaning, major funding agencies are enacting policy making it the centerpiece. For example, the National- Science Foundation, Institutes of Health (NIH), and Institute for Education Sciences have made translational research a priority. We hope that this work translates into practice through the awareness teachers have from participation in and discussion of the activities. The new teacher knowledge of collaborative engagement through these tasks will develop a sense of importance for precise language and this realization will translate into encouraging their students to work cooperatively and to complete tasks using precise language. Further, we hope that professional development providers will also need to examine this evidence and add a component to all PD that emphasizes the development of precise STEM language.

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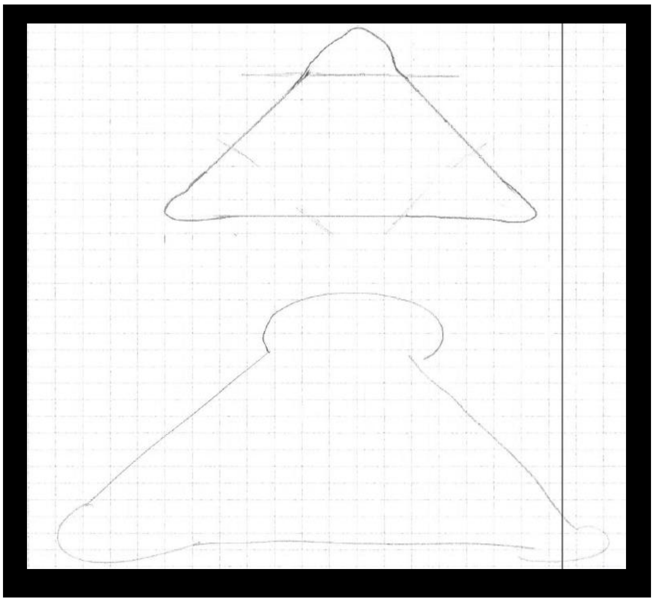
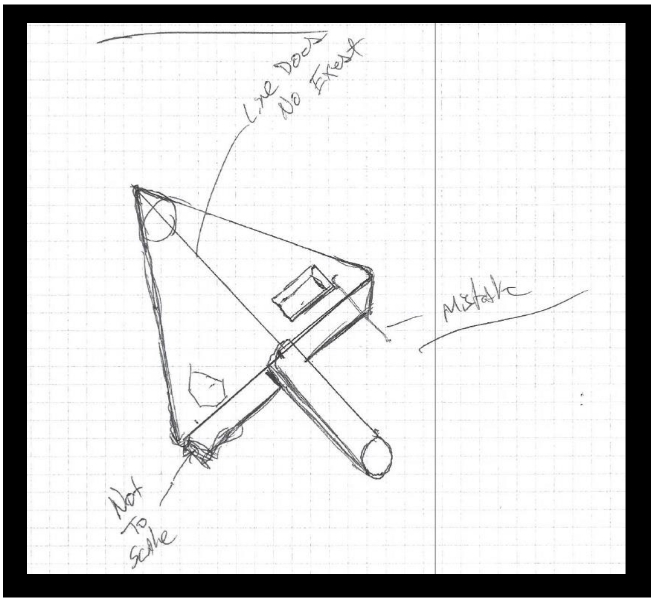
Appendix

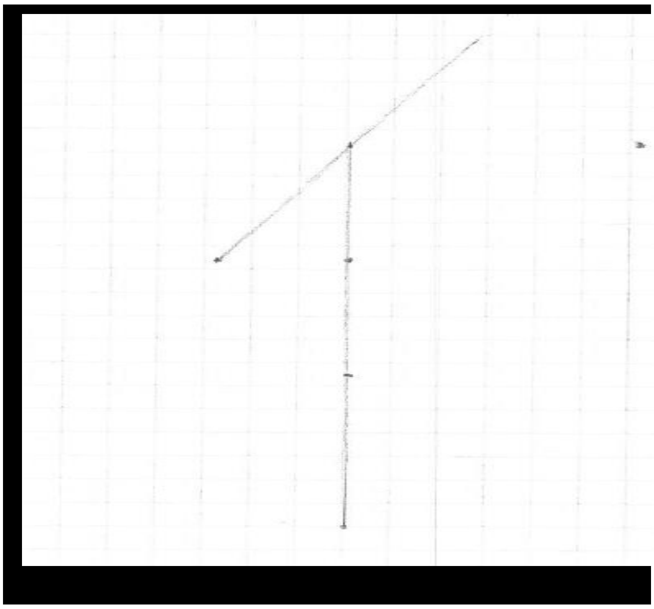
Group 9



Group 5



Group 6



Group 4