CALIFORNIA POLYTECHNIC STATE UNIVERSITY SAN LUIS OBISPO

Design and Development of an Interactive Materials-Based Learning Kit for K-4 Grade Levels

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Abstract

DESIGN AND DEVELOPMENT OF AN INTERACTIVE MATERIALS-BASED LEARNING KIT FOR K-4 GRADE LEVELS

By: Thomas Agasid, Santiago Caceres, and James Woodhead

The Materials Safari Adventure kit was designed to help introduce basic materials concepts to young audiences in kindergarten through fourth grade levels. The primary goal of this project was to design a tool to spark an interest in materials science for young children, while revealing the field of materials science to parents and educators. The final kit design incorporates a safari theme to encourage imagination and promote self-directed learning through the interaction with materials. Materials were selected to showcase a range of properties within three materials classes: metals, polymers, and natural woods. A total of 9 materials were chosen for the kit, including: a-36 mild steel, 6061 T6 aluminum, 360 alloy brass, clear cast acrylic, ABS plastic, rosewood, oak, and balsa wood. The metal materials were water jet cut followed by hand filing and sanding, the woods and acrylic were laser cut, and the ABS was rapid prototyped using a 3-D printer into the profile shapes of various safari animals. The kit consists of three testing stations designed to examine weight, density, and magnetism. Prototype testing was conducted at the Cal Poly child development lab and the San Luis Obispo Children's Museum. Through prototype testing, we gained a greater understanding of our user and tailored the kit to better suit their learning needs. Additionally, testing verified the sizes of the animal pieces, ⅜" thick, between 1 to 2.25" in width, and 1.2" to 2.25" in height to be appropriate even for our youngest users. The safari theme was able to cultivate interest and motivation in users. The Materials Safari Adventure was able to successfully demonstrate and portray educational concepts presented at the testing stations, verified by the user's ability to correctly answer application driven questions.

1. Introduction

The Materials Safari Adventure was designed, prototyped and assembled as an educational kit that takes on a new, creative way of teaching materials-related topics to young audiences in the K-4 grade levels. The primary goal of the project was to spark an interest in science for young children, while introducing the field of materials science to parents and educators. A materials safari theme was used to encourage young users to engage in the activities in a fun and interactive setting. One of the more difficult education subjects to introduce to children is the field of physical sciences. Demonstrating material properties can greatly aid in children's comprehension of these concepts. Weight, density and magnetism were directly addressed in the kit to aid educators in conveying these subjects. Through hands-on experience, users will be able to explore different materials and their properties. The kit could potentially serve as a teaching aid for elementary schools, preschools, home schools, museums, and outreach events.

Objectives

- To promote learning and exploration of materials properties
- To teach children that material properties can be observed, predicted, and measured
- To introduce young children to physical sciences in a way that sparks their curiosity and maintains their attention
- To build a strong foundation for science-based learning

1.1 Stakeholders

The kit was designed to be used at the San Luis Obispo Children's Museum (SLO CM), the Cal Poly Child Development lab (CD), and the Cal Poly Materials Engineering (MatE) department. Together these locations formed our stakeholders.

The SLO CM is an informal learning site where kids can go to learn about traditional science concepts without the classroom feel. Their stakeholders include the children users ages 3 to 9 years, who will directly interact with the kit, their accompanying adults who brought them to the museum, and the museum staff, who will help facilitate the activities within the kit.

The Cal Poly CD lab is an on-campus preschool that is also used as a lab for the child development and psychology department. The stakeholders at the CD lab include the children ages 3 to 5 years, who will interact with the kit, the college-staff, and the faculty who will help facilitate the activities within the kit.

The MatE department holds numerous outreach events with the community, working closely to excite kids about science and engineering. The stakeholders at these events would include the kids who interact with the kit and the Cal Poly faculty and students who help run the activities of the kit.

1.2 Broader Impacts

Our kit was originally designed with K-4 graders in mind, but the project impacts a much larger audience. Collectively, the age range for the user is from 5 to 9 years. However the kit is designed to include instructions and background information for parents and facilitators to help teach science concepts to the kids. Because the facilitator is responsible for transcending the information to the users, they will also learn the science concepts for each of the activities within the kit.

By using this unique tool to teach traditional science concepts, we hope to encourage science-based exploration. This method can create awareness and motivate users to keep learning and exploring similar science-related fields. This has the potential to spark a growth in math, science, and engineering majors in universities down the road. Furthermore, by working with the SLO CM and at MatE outreach events, we can build relationships between the MatE department and the surrounding communities.

1.3 Background

In Kindergarten through fourth grade, children rely heavily on their sensory levels to gather information.[1] Using sight, sound, touch, smell and taste, children gain information about their physical surroundings. These interactions lay the foundation of a child's knowledge, and are important for supporting further abstract knowledge.[1] Informal environments, or non-classroom settings, have the potential to allow users to develop awareness, interest, motivation, social competencies and practices.[2] Classrooms settings are not the only designated places for learning. At younger ages, local museums, basketball courts, and even homes are places where knowledge is gained. Sensory learning is not limited to the classroom, as knowledge can be gained in many non-traditional environments. These places are often overlooked and are rarely considered as learning sites.

Non-classroom environments are full of real-world phenomena. The problem is that these environments offer no explanation for questions that may result from experiences. Most formal classroom settings do not include demonstration processes that allow children to physically see and experience concepts. It is easier for children to understand concepts/real-world phenomena when they are displayed then theoretically explained.[2] Designed spaces, especially those outside of the classroom, support science learning. Kits and exhibits combine the advantages of informal and formal learning environments. Demonstrating real world phenomena while also providing explanations is a more effective method of teaching science. Specifically, the concept of density possesses a greater challenge for children because of the inherent incongruence that exists in the relationships between mass, volume, and density.[3] For this is reason, we chose to create a kit for introducing the physical sciences to young audiences.

An informal designed space also supports and encourages more self-directed learning.[2] Free-choice or self-directed learning is a term that recognizes the unique characteristics of such learning: free-choice, non-sequential, self-paced, and voluntary.[2] A vast majority of the learning that occurs outside of school involves free-choice learning - learning that is primarily driven by the unique intrinsic needs and interests of the learner.[4] Free-choice is synonymous with self-directed learning; both are influenced by

intrinsic motivation of the user to explore their personal interests. This form of learning does not follow the traditional learning structure found in schools or classrooms. Instead, it gives users the freedom of learning by pursuing their desires at their own pace. This process provides a unique educational experience for each user by allowing for non-sequential, self-paced, and voluntary learning. Classroom settings average the needs of the whole, rather than catering to single individuals. Self-directed learning is crucial for younger audiences since their primary motivation comes from interest and comfort in the learning environment. Since environments have such a significant impact on how interested the user will be with any learning tool, focusing on children's persona in relation to the kit is essential.

The National Academies Six Strands of Informal Learning was a major resource for developing the foundation of our project (Table I).[2] An important principle to consider when developing an informal learning tool is to have specific learning goals in mind. Teaching the physical sciences and scientific methodology were two of the main objectives. A guiding principle in developing the kit was trying to create an interactive setting in order to generate interest and motivation in the user. Providing multiple avenues of interacting with the kit helped in creating an effective informal learning environment. An investigative process would allow users to generate their own scientific evidence in order to prove or disprove their original assumptions. The kit should also lead users to reflect on how scientific evidence can be produced and used. Allowing users the opportunity to interpret learning experiences relative to prior knowledge, experience, and interests contributes to the tools overall effectiveness.

Table I: Six Strands of Learning[2] and Associated Design Principles

Six Strands	Design Principles
1. Interest and motivation 2. Understanding scientific explanations 3. Generating scientific evidence 4. Reflecting on science knowledge in society 5. Participating in scientific methods 6. Development of identity in science	- Have specific learning goals in mind - Be interactive - Provide avenues for learners to engage with presented concepts - Facilitate science learning in multiple settings - Prompt and support users to interpret their learning experiences relative to prior knowledge, experience, and interest

In addition to providing a supportive learning atmosphere, an effective teaching aid must focus on relevant educational concepts. Our team focused on applying appropriate educational subject matter in our kit by addressing the California Education standards. These call for a multitude of scientific concepts for Kindergarten through fourth grade. The kit was geared toward the physical sciences and the investigation and experimentation components of education requirements (Table II).

Table II: How CA Education Standards are Addressed

Education Standards	How to address the standard
Physical Sciences: Students can predict, observe, and measure material properties including color, size, shape, weight, flexibility, and magnetism	- Users can predict, observe, and measure material properties - Engage in hands-on learning
Investigation & Experimentation: Students develop their own questions and perform investigations	- Investigate material properties through comparison and sorting - Make prediction and use guided interactions to validate assumptions

Informal environments should be developed through community-educator partnerships.[2] Relationships between the community and educators need to be established in order to properly design and develop learning aids. Educational tools and materials are recommended to be developed through iterative processes and involve learners, educators, designers, and experts in science, including those in human learning and development.[2] The development process requires a cooperative effort between educators, designers, and users. It was important that the stakeholders were continually involved with the design process to create the most effective learning tool for our user.

2. Design Constraints

Understanding the user and their needs is one of the first and most important steps in any design project. A needs assessment was conducted to gain valuable insight about our user. Following the assessment, functional design requirements were defined for two components of the project: materials engineering and child development. The functional requirements were split between the two categories because meeting the requirements of the user's interaction with the kit differed from the engineering aspects of the designing the kit.

2.1 Materials Engineering Functional Design Requirements

The materials engineering requirements were broken down into five categories: materials selection, manufacturing, durability, safety, and economic constraints (Table III). The materials selection required a number of materials with a range of properties to help portray concepts at testing stations. Materials should vary in density, weight, and magnetic properties to show how materials behave differently even within material classes. The materials pieces needed to be designed to endure frequent contact without being hazardous to the user. The shapes of each of the animals would need to ensure that pieces could not be easily broken or pose as a potential safety concern such as sharp or pointy edges. Due to the size of the project, the manufacturing process had to be selected for a small number of materials samples to be cut to minimize cost. Additionally, the budget limited the total cost of the kit to below $500. After applying these constraints the appropriate materials, manufacturing process, and

suitable number of material pieces were selected, while considering safety of the user and budget limitations.

Table III: Materials Engineering Functional Design Requirements

Attribute	Design Requirement
Materials Selection	- Include broad range of materials and material properties - Include 2 or 3 materials from each class: metals, polymers, and woods - Use non-toxic materials
Manufacturing	- Inexpensive shaping method - Small scale production: low number of parts
Durability	- Withstand continual user interaction - Includes replacement pieces
Safety	- No sharp or hazardous pieces - Size and weight of pieces must be safe for users
Cost	- Total cost of kit < $500

2.2 Child Development Functional Design Requirements

The child development requirements were separated into three attributes: the Six Strands of Learning, California educational standards, and user interactions (Table IV). The Six Strands of Learning were considered in the design to maintain user interest and interactions while effectively demonstrating concepts. To address relevant educational concepts we applied the California educational standards for K-4 students. The user interactions were adopted from the San Luis Obispo Children's Museum's exhibit production guidelines to ensure the kit was able to accommodate our users.[5]

Table IV: Child Development Functional Design Requirements

Attribute	Design Requirement
6 Strands of Learning 1. Interest and motivation 2. Understand scientific explanations 3. Generate scientific evidence 4. Participate in scientific methods 5. Reflect on science knowledge in society 6. Develop an identity in science	1. Interactive and hands-on learning aid. Create fun atmosphere to captivate interest. Encourage continual interaction with kit. 2. Verification of learned concepts through activities, include explanations of concepts 3. Provide necessary tools to gain science knowledge 4. Design activities to encourage scientific exploration 5. Relate concepts to current applications 6. Introduce field of materials science to users
CA Education Standards 1. Physical sciences 2. Investigation and experimentation	- Demonstrates difference in material behavior for density, weight, and magnetism - Predict observe and measure density, weight, and magnetism
User Interaction 1. Multisided 2. Multiuser 3. Accessible to children and adults 4. Unique 5. Minimally facilitated	- Individual testing stations to accommodate multiple participants - Adaptable to any environment - Provide new and interesting method of teaching concepts - One facilitator can run kit

3. Methods and Materials

3.1 Project Evolution

Materials Zoo

We began the project by developing designs for an interactive, engaging, and educational exhibit for the SLO Children's Museum. The team went through an iterative process of brainstorming and presenting ideas to the board members of the San Luis Obispo Children's Museum. This led to our first concept of a Materials Zoo, an interactive exhibit that mimics the look and feel of a zoo (Figure 1). The Materials Zoo concept accomplished two main objectives. First, to create a project with an environment K-4 students would be familiar with. Second, to display the basic differences in materials properties through interaction and challenges. The design was meant to guide the user into discovering how to select appropriate materials for an application. It contained a free play area for the user to independently interact with materials and challenged them to select for application driven properties to encourage learning. The zoo theme was incorporated to allow audiences to use their imagination and promote self-directed learning through the interaction with materials. The exhibit would include polymers, natural materials, and metals in silhouettes of common zoo animals intended to show the user the differences and similarities between the material categories.

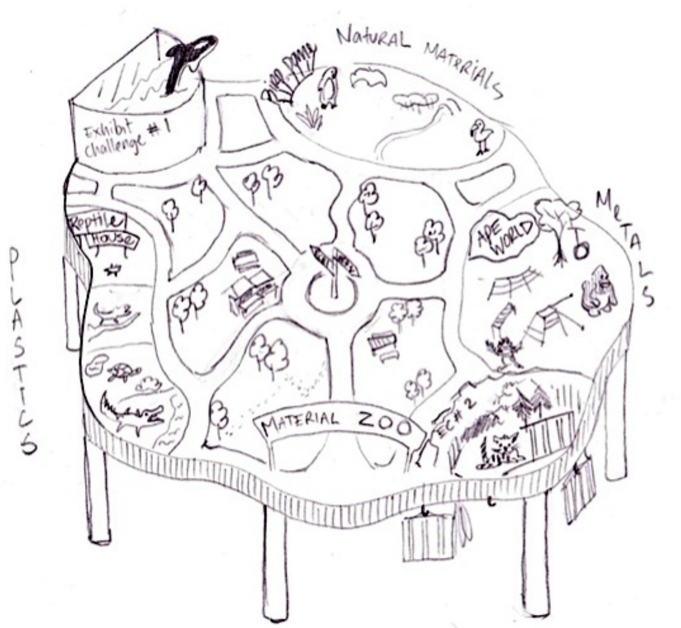


Figure 1. A Sketch of the Materials Zoo, the first conceptual design for the project.

The purpose of free play was for the user to interact with the different materials presented to them. Interaction occurred through physical hands-on learning in order to gain knowledge about material properties. In the application challenges, users could use the knowledge gained from interacting with the materials to select the appropriate materials based on the needs and requirements of an application. Applications were based on a clear relation to material properties and included common zoo animals.

The first application was to choose the correct material to make the bars of a tiger cage. The challenge in this application was to select the strongest material for the tiger cage bars, so the tiger wouldn't be able to escape. The second application was to select an appropriate material for the viewing panel of an aquarium. Here the user would have to determine which material displayed the best optical properties to see through to the marine life in the aquarium.

The issue we needed to address from our first design was the materials selection process. Consulting with board members from the SLO Children's Museum gave us framework of how to adapt our project to better suit our user. The materials selection challenges for the Materials Zoo exhibit could have been too complex for our younger users. We also had a couple of problems: first, certain properties for our challenge applications required destructive or otherwise difficult testing of materials, and second, that there was only one right answer to the challenge. We decided to change the structure of our project from application and challenge driven concepts to displaying the similarities and differences in materials.

With these changes the Materials Zoo evolved into SLOanda, a safari themed exhibit again aimed to introduce audiences to the world of materials (Figure 2). This design had the same foundation of an interaction-based exhibit with a free play area and silhouettes of animals made from different materials. However, the challenges from the original design became testing stations. As in the first design we wanted to display a familiar environment and planned on accomplishing this by including grass, trees, rivers, mountains, rocks, and other accessories to mimic the appearance of an African safari. SLOanda consisted of four sections: two testing stations, a designated free play area, and an interchangeable section allowing for facilitated activities. Testing stations and activities were integrated into the exhibit to display various material properties through the same process of interaction from the first design.

Figure 2. A sketch of SLOanda, the second conceptual design for the Children's Museum.

Due to several unresolved issues, the design of our project changed from a tabletop design to a portable kit. There had been problems with the museum's setting including occupying floor space, losing essential components or users moving them to other exhibits, and undesired maintenance by the museum staff. A portable design solved the problem of spatial limitations at the SLO Children's Museum and also enables our project to reach a broader audience. Also, we were advised to simplify the design of our project since fabrication and construction issues would have become significant challenges given our time constraint. After considering those recommendations we adapted our design to contain three testing stations that each portrayed one fundamental and relevant concept. These last modifications produced our final design.

3.2 Final Materials Kit Design

The Materials Safari Adventure kit contains material samples, testing stations, challenge cards and a unifying safari mat (Figure 3). All aspects of the kit are designed to portray an African landscape. Included in the kit are animal pieces comprised from nine different materials in four animal shapes: a crocodile, elephant, lion, and giraffe. These animal pieces are designed to portray the different properties of the materials at the three independent testing stations. The testing stations focus on three materials properties: weight, density, and magnetism. A deck of challenge cards are provided at each station to help guide the facilitator and user through an informative investigation of material properties. Additionally, a deck of challenge cards labeled the Sorting Savannah are included to guide users through categorizing and visually inspecting the animal pieces. All of the necessary components to run the activities are provided in the kit.

Figure 3. An example layout of the Materials Safari Adventure with the animals, testing stations, and mat.

Material Selection

The Cambridge Engineering Selector (CES), a materials selection software program, was used to analyze a wide range of materials and perform a materials selection based off our selection criteria. Three main design constraints influenced the selection of our materials: safety, cost, and manufacturability. Additionally, all toxic or hazardous materials were constrained and prevented from being selected. Figure 4 shows the wide range in density and price for the materials.

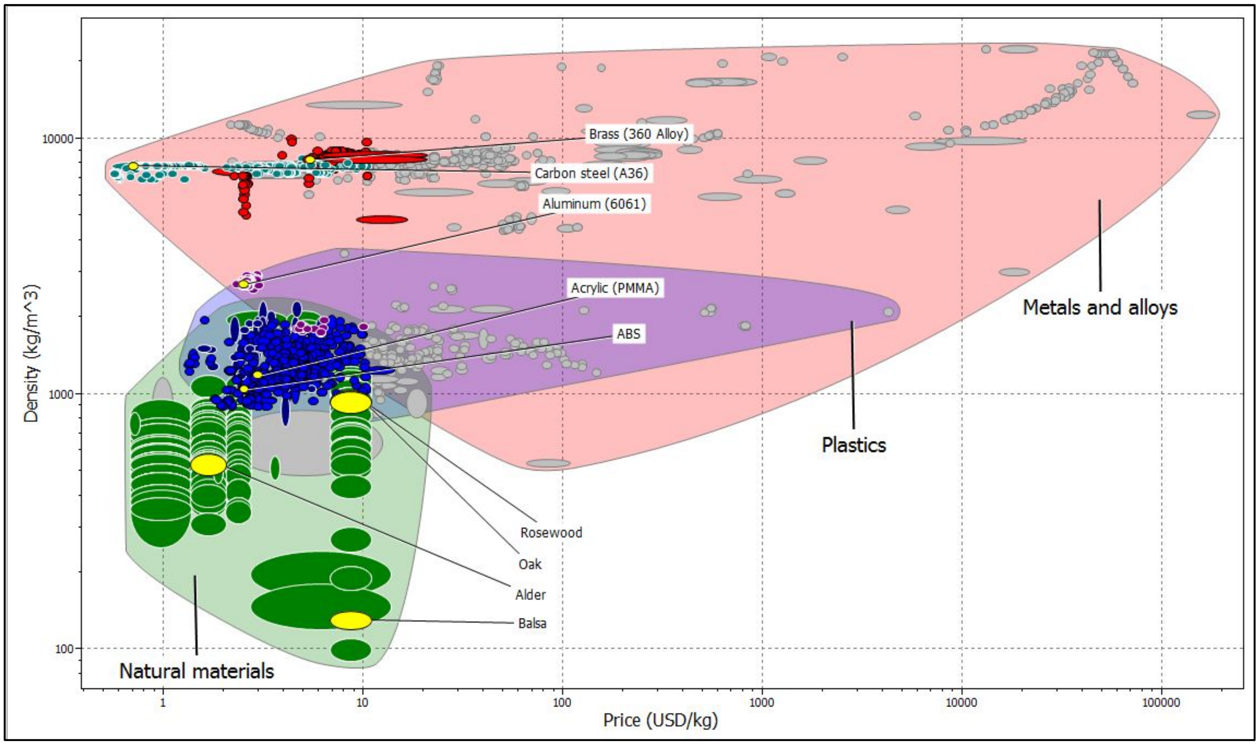


Figure 4. CES plot for materials selection which examined the density to cost of the materials.

Using CES we were able to limit the selection to materials that would be most cost effective, while providing a wide range in the properties demonstrated at the testing stations. In addition to meeting the initial design constraints, priority was given to materials that were donated and could be easily fabricated into animal shapes. Materials were selected from three different material classes: metals, polymers, and woods. The final set included nine materials: 6061-T6 aluminum, a-36 mild steel, 360 alloy brass, clear cast acrylic, ABS plastic, rosewood, alder, balsa, and oak woods.

Material Samples

Each material piece was cut in the shape of a safari animal silhouette. The animal shapes were designed to generate interest by creating a familiar and fun environment for the user to explore material properties. Two different sizes of animals (child and adult) were incorporated through the theme. This added variety while introducing a change in volume with a constant material. Figure 5 shows the combination of the materials, their shapes, weights, and which are magnetic or floating.

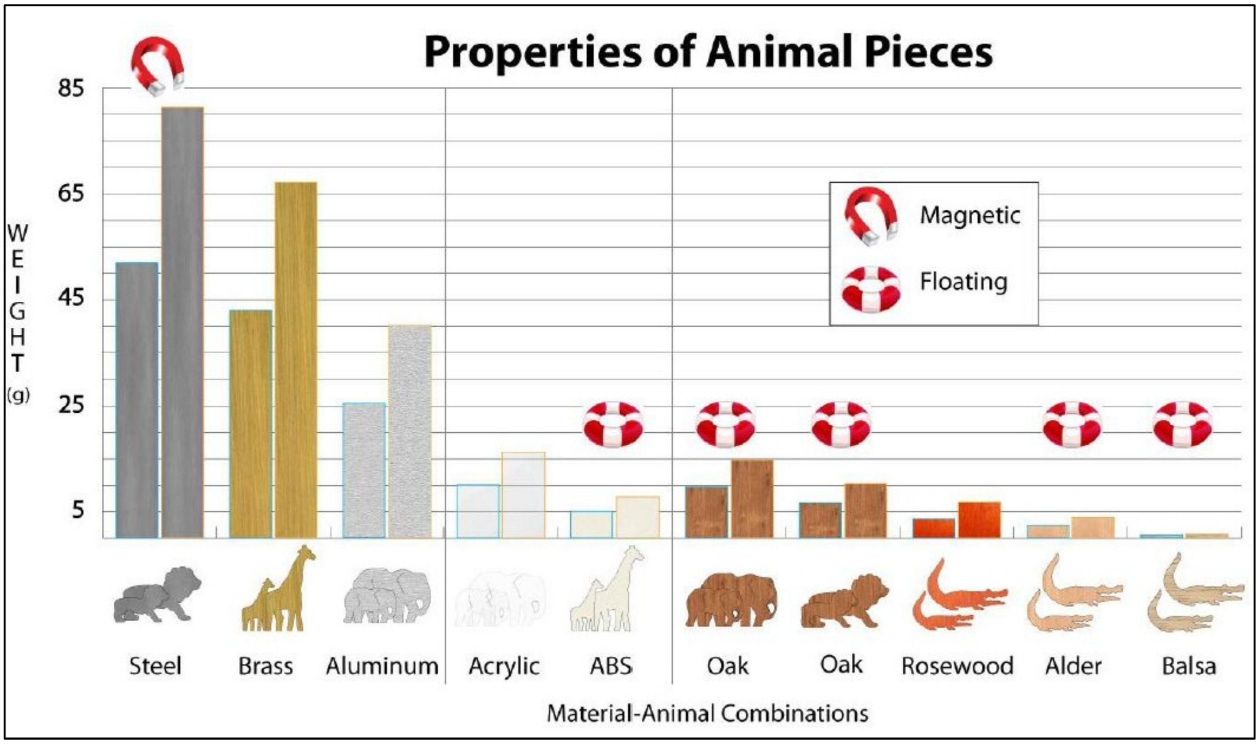


Figure 5. Graph of material and animal combinations showing their range of selected properties.

The Materials Safari Adventure contains one set of two adult and two child sizes for each material. The balsa and alder crocodiles sets were doubled in order to balance the weight of a metal at the balance tree station. Animal material combinations were selected to work with challenge card questions that demonstrate relevant phenomena.

Testing Stations

Balance Tree: Weight

The Balance Tree station includes a wooden scale that allows users to compare materials of varying densities and volumes (Figure 6). By loading the scale with the materials provided, users will discover the largest material by volume is not always the heaviest. Through hands-on interaction with the materials, users will be encouraged to think critically about why an object with a larger volume may be lighter than an object with a smaller volume. Children that interact with this station will be encouraged to evaluate their initial assumptions concerning material, volume, and weight.

Figure 6. The Balance Tree shows the weight of aluminum elephant is more than that of the oak elephant.

Watering Hole: Density

The Watering Hole station includes a plastic tub to resemble a pond and allows users to examine the density of different materials relative to the density of water, 1.0 g/cm^3 (Figure 7). The tub is filled with water and users will be able to see which materials float or sink and discuss the reasoning behind why certain materials float. This station compliments the Balance Tree to explore the relationship between weight and density. Figure 5 shows the materials that will float.

Figure 7. Watering Hole showing the ABS, balsa, and the oak animals floating, while the acrylic, rosewood, and aluminum animals to be sinking.

Mud Pit: Magnetism

The Mud Pit station includes a plastic tub filled with dry beans and magnetic wands that allow users to discover which materials are magnetic (Figure 8). The material samples are buried beneath the dry beans, which act as “mud” to conceal the materials. Users are then asked to find the animals with the magnetic wands. The children notice that only one of the materials are magnetic (a-36 Steel), and more specifically only one of the metals.

Figure 8. Mud Pit showing the magnetic lion being attracted to the magnetic wand.

Challenge Cards

Challenge Cards are provided to guide user interactions with the testing stations and sorting (Figure 9). Questions and activities on the challenge cards are intended to promote investigation, experimentation, and reinforce the concepts demonstrated at each testing station. The activities on the cards motivate the user by presenting goals for them to overcome and answers to find. Challenge cards include specific questions designed to make the user think critically about material properties revealed through empirical evidence. Challenge cards are ranked based on the difficulty of each question or activity. This ranking system is designed to help the facilitator ask appropriate questions for the age and level of each user and be able to easily progress to harder questions as the user gains an understanding of the concept presented at each testing station. Deciding whether something is always true, sometimes true, or false is how users engage in critical thinking.

Figure 9. Example of the Challenge Cards that will be provided with the kit.

The Sorting Savannah is a set of challenge cards related to grouping and sorting the animal pieces. Through these challenges the user is introduced to the range of materials. This set of challenge cards can be considered an independent sorting station that does not have a defined location.

3.3 Prototype Testing the Kit Design

Prototype testing was conducted at Cal Poly's Child Development (CD) lab and the San Luis Obispo Children's Museum (CM). The CD lab offered us a chance to learn about our younger users (ages 3-5) and receive feedback on our design from child development professors and students. The CM offered a wider age range and a competitive environment filled with other exhibits to learn from. Initial test were conducted at the CD lab to understand how users would interact with the wooden scale and material samples. Safety was the main concern during initial rounds of prototype testing. The testing procedure involved having one of us facilitate and manage the station while the rest of the team made observations. As we developed more of the kit and better understood our users we began to alternate between testing at the CM and CD. The testing process offered valuable insight about our users interest and interaction with the kit.

3.4 Fabrication

Animal Pieces

After selecting the optimal materials and the animal shapes, we needed to find ways of manufacturing the silhouettes. When selecting the appropriate fabrication processes for the nine materials, there were several criteria that needed to be considered.

- The material – including density and thickness
- Whether the fabrication method could effectively and accurately cut our design
- Cost of fabrication method
- Amount of fabrication time required
- Availability of technique and material

From this set of criteria, three different methods were chosen and used to produce the animals for the kit. All of the metals were water jet cut, all of the woods plus the acrylic were laser cut, and the acrylonitrile butadiene styrene (ABS) plastic was rapid prototyped on a 3D printer. The animals were hand sketched, then traced in AutoCAD to create files that could be used for Computer Numerical Control (CNC) machining (Appendix A). Figure 10 shows the schematics for water jet and laser cutting manufacturing processes.

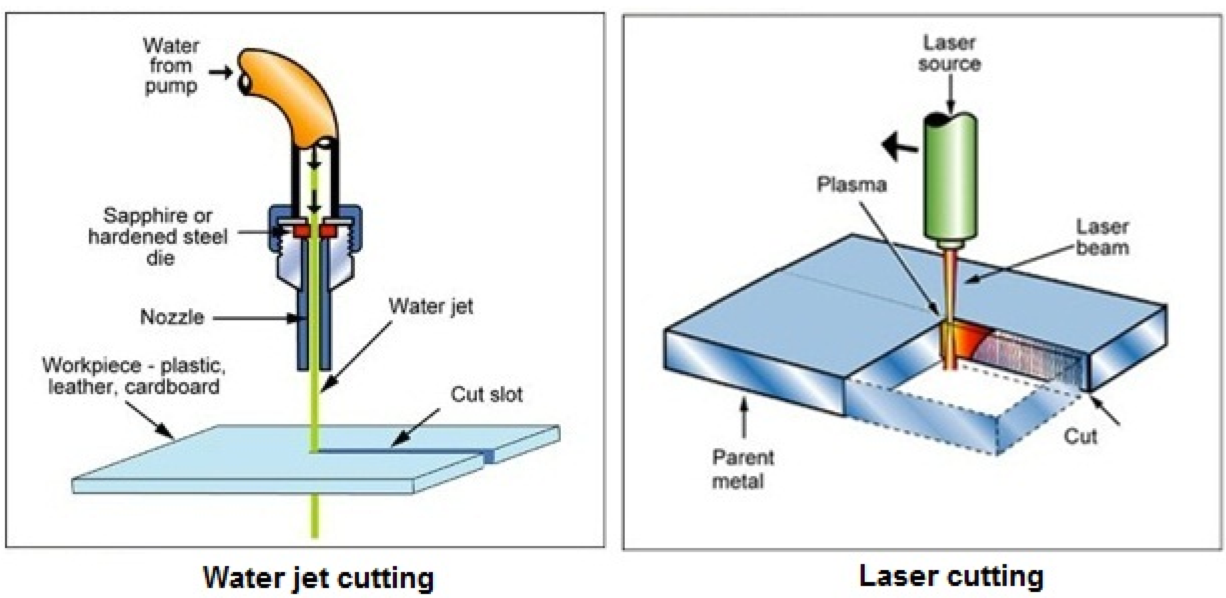


Figure 10. Schematics of water jet and laser cutting.

The metals were cut by Water Jet Central (WJC) located in Paso Robles, CA. WJC provided the 6061-T6 aluminum and the a-36 mild (low carbon) steel, while the 360 alloy brass sheet was purchased from Mc-Master Carr and sent in to be cut. Water jet cutting was selected because this method could easily cut the shapes at a relatively low cost and could produce the animals in a short amount of time. Following water jet cutting, all animals had sharp edges which needed to be removed. The animals were filed and

sanded to provide a smooth finish acceptable for use within the kit (Figure 11). To prevent the plain carbon steel animal pieces from rusting, all steel elephants were coated with a Rustoleum Rust Inhibitor clear coat. Two spray coats were applied to the entire surface of the elephant.

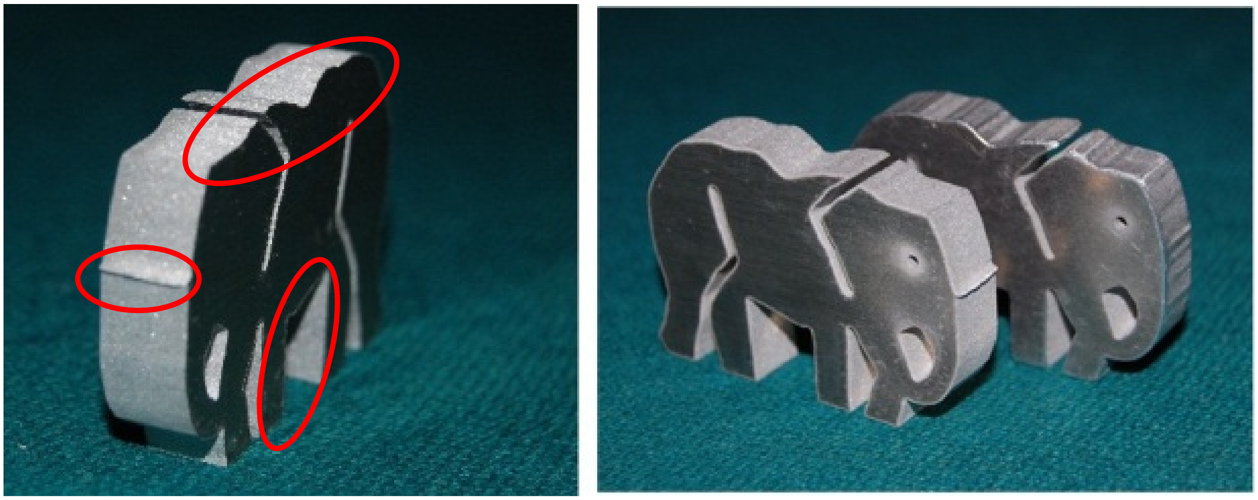


Figure 11. Left image indicates sharp edges; right image shows sharp edges relative of a newly water jet cut versus a filed and sanded aluminum elephant.

Budget constraints caused the team to look for cost-free methods of cutting the other materials. The woods and the acrylic were cut in the Mustang ‘60 Shop on the Cal Poly campus using a Universal Systems High Powered Density Focusing Optics laser cutter. Due to varying densities of the woods, different laser settings were required to cut each material (Table V). The machine’s settings allowed us to control the power of the laser, the speed at which the laser cuts, the focal length of the laser, and the number of times the machine cuts the image.

Table V: Laser Cutting Settings for Wood and Acrylic Animal Shapes

Material	Power	Speed	# of passes
Balsa	60%	3.0	1
Oak	70%	3.0	6
Alder	80%	4.0	2
Rosewood	100%	4.0	8
Acrylic	80%	3.0	3: z height move of +0.05” per pass

The laser cutter at Mustang ‘60 was set up more as a printer. As long as the file could be read in Adobe Illustrator, the laser could cut or engrave onto the material (Figure 12).

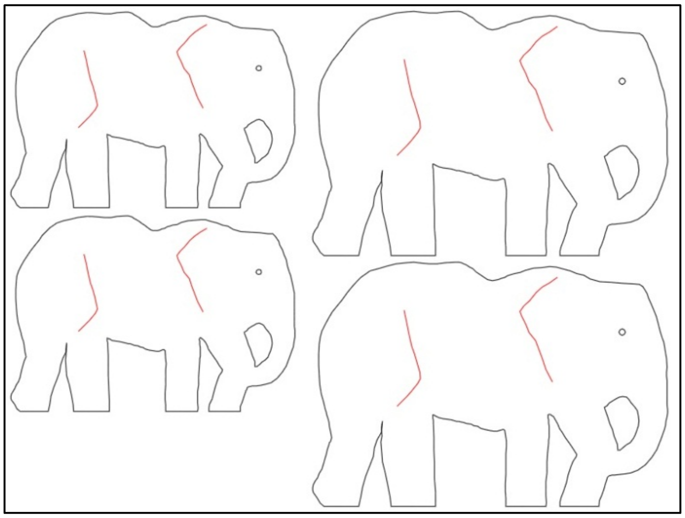


Figure 12. An example of an Adobe Illustrator-readable file that was used to cut out the parent and child animals on the Universal Systems laser cutter.

In the specific case of rosewood, the material was originally ½" thick and needed to be planed down to 3/8". A table top router also in the Mustang '60 shop was used to reduce rosewood's thickness to approximately 3/8". Animals piece were sanded using a combination of 320 and 400 grit sandpaper to create a smooth finish on the cut edge of the material. Following sanding, all wood materials were coated with three or four layers of a clear varnish. The varnish would help prevent the woods from absorbing water, protect against wear, and rotting (Figure 13).

Figure 13. A comparison of the balsa crocodiles; one with the varnish and one without.

The ABS giraffes were printed using a Stratasys Fused Deposition Modeling (FDM) 3D printer through the Industrial Technology department on the Cal Poly campus. A solid model was created in SolidWorks using the AutoCAD drawing and saved as an .STL file to be used by the 3D printer.

Testing Stations

Fabrication of the testing stations involved finding and purchasing appropriate components for each station, and modifying the components to fit into the theme. Safety and cost where the two important constraints when selecting suppliers for the Materials Safari Adventure. A wooden, child-safe scale was purchased for the balance tree station. Alder was then laser cut into the shape of a tree and attached with epoxy to the top of the balance. Plastic bowls where purchased for the mud pit and

watering hole. After the beans and magnetic wands were purchased for the mud pit, brown felt was used to incorporate the bowl into our theme. The felt mat required the most fabrication and was necessary for unifying the three testing stations. The mat was created by cutting out safari landscape features out of colored felt and placing them onto a fleece base. Fleece was chosen because of its soft feel and better resistance to water when compared to felt. All the parts to the kit were packaged in a shallow, easy to carry plastic bin. Figure 14 shows the portable bin with everything needed to run the Materials Safari Adventure stored within.

Figure 14. The Materials Safari Adventure kit packed in the portable container.

4. Results and Discussion

4.1 Materials Engineering

Safety

Filing and sanding metal animal pieces proved to be a success measure as prototype testing with young users did not show any problems with harming their hands while handling the animals. The process of hand filing and sanding was slow and tedious. A different method of eliminating the sharp edges is needed if multiple animal sets are to be made. Metal tumbling could be used as a possible solution because it is a simple tasking of placing the machined parts into a vibrating container of smaller metal beads. This method would yield child-safe animal pieces requiring less man power, a quicker turnaround time, and edge uniformity across all materials.

All of the wood materials were sanded because the laser cutter left a char layer on the cut edges along with a distinct scent. Sanding the edges removed much of this layer, as well as the burnt smell, and created a uniform edge finish amongst the animal pieces.

All animal pieces were to designed to be appropriately sized for our user's hands and not pose as a potential choking hazard. Additionally, our team found out through Dr. Jipson that children stop putting items in their mouth around age of 2, which reduces the risk of users attempting to consume pieces of the kit.

Budget

The cost of the kit can be broken down into two categories: the animal pieces and the components of the kit (Table VI). Animal pieces include the cost of raw materials and their fabrication. The only raw materials purchased for the project were the brass, acrylic, and the balsa. The aluminum and steel animals were cut from scrap metal provided by Water Jet Central. The oak and alder were donated by Adriana Caceres, rosewood was given to us by Dr. Chen, and the ABS plastic giraffe was printed free of charge by Philip Chehade.

Table VI: The Cost of The Materials Safari Adventure Kit: Raw Materials & Fabrication

Animal Pieces	
Item	**Cost**
Metals	
6061-T6 Aluminum	$33.33
a-36 Mild Steel + Anti-rust spray	$33.33 + $3.20
360 Alloy Brass (Raw and fab)	$61.73 + $33.33
Polymers	
Acrylic	$17.60
ABS Plastic	---
Woods	
Alder	---
Balsa	$5.27
Oak	---
Rosewood	---
Kit Components	
Item	**Cost**
Balance Tree	
Scale	$32.09
Watering Hole	
Plastic Tub	$1.50
Mud Pit	
Plastic Tub	$1.50
Magnetic Wands	$14.17
Beans	$9.69
Safari Themed Place Mat	$22.06
Plastic Kit Container	$8.50
Total	$277.30

The only money spent on the fabrication of the animals was for the set up and cutting time of the water jet cut animals, plus the rust inhibiting spray for the steel animal. We were not charged for material because the animals were cut from scrap that typically would have been thrown away. There was no cost for laser cutting because the cutter was provided by Cal Poly and we did the cutting ourselves. The clear wood varnish was donated to the team.

The final costs were associated with the components of the testing stations, the safari themed place mat, and the container transportation. The total cost of the prototype kit was $277.30, which was within the budget of $500.

Materials Selection

The first set of animal pieces that were water jet cut was a stainless steel elephant and an aluminum lion. Through the first round of prototype testing we found that stainless steel would not work as a material in our kit and should not be used for the elephant shape. Stainless steel was initially chosen over plain carbon steel because of its corrosion resistant properties. Because the design of the elephant had holes and crevices, the material needed to be corrosion resistant to prevent rusting. Additionally, the elephant was the largest of the animals and with the densest material, we had created a piece of the kit that was quite heavy and created a safety concern. The solution to the corrosion and weight problem came in the decision to switch the material from the stainless steel to aluminum. The material swap worked out because aluminum has outstanding corrosion resistant properties and has a density of 2.7 g/cm^3 (roughly 3 times less than that of a-36 steel, 8.03 g/cm^3). The decrease in density would absolve the weight and safety concern as well. We also realized the stainless steel was not magnetic and a magnetic material was needed for the Mud Pit station. The kit was not able to include both stainless and plain carbon steel because this would increase cost.

The initial round of prototype testing revealed that the kit needed more than one set of animals. While running three testing stations simultaneously, we needed to make sure the appropriate materials would always be available for specific testing stations. The Mud Pit needed to have the steel lion or the users would simply be sifting through the tub of beans. The Watering Hole required the presence of the rosewood crocodiles to show that not all woods float and that materials within the same class can have a range in properties. Additionally, the presence of the aluminum elephants was necessary to show materials that are largest by volume are not always the heaviest. Since animal pieces are not constrained to specific stations, when multiple users interact with the kit at one time, a single user could potentially not have the appropriate range of materials. Doubling the number of animal pieces included in the kit reduced the possibility of not having the necessary range of materials at each station.

Manufacturing

Our initial batch of fabrication of the animal shapes revealed issues we had to overcome. Initially we had assumed the 3/8” acrylic was too thick for laser cutting, therefore we opted to have the animals water jet cut. However, during the cutting process, the water jet left the child sized acrylic elephants cracked, and in one case leaving a section of the stock sheet cracked (Figure 15).

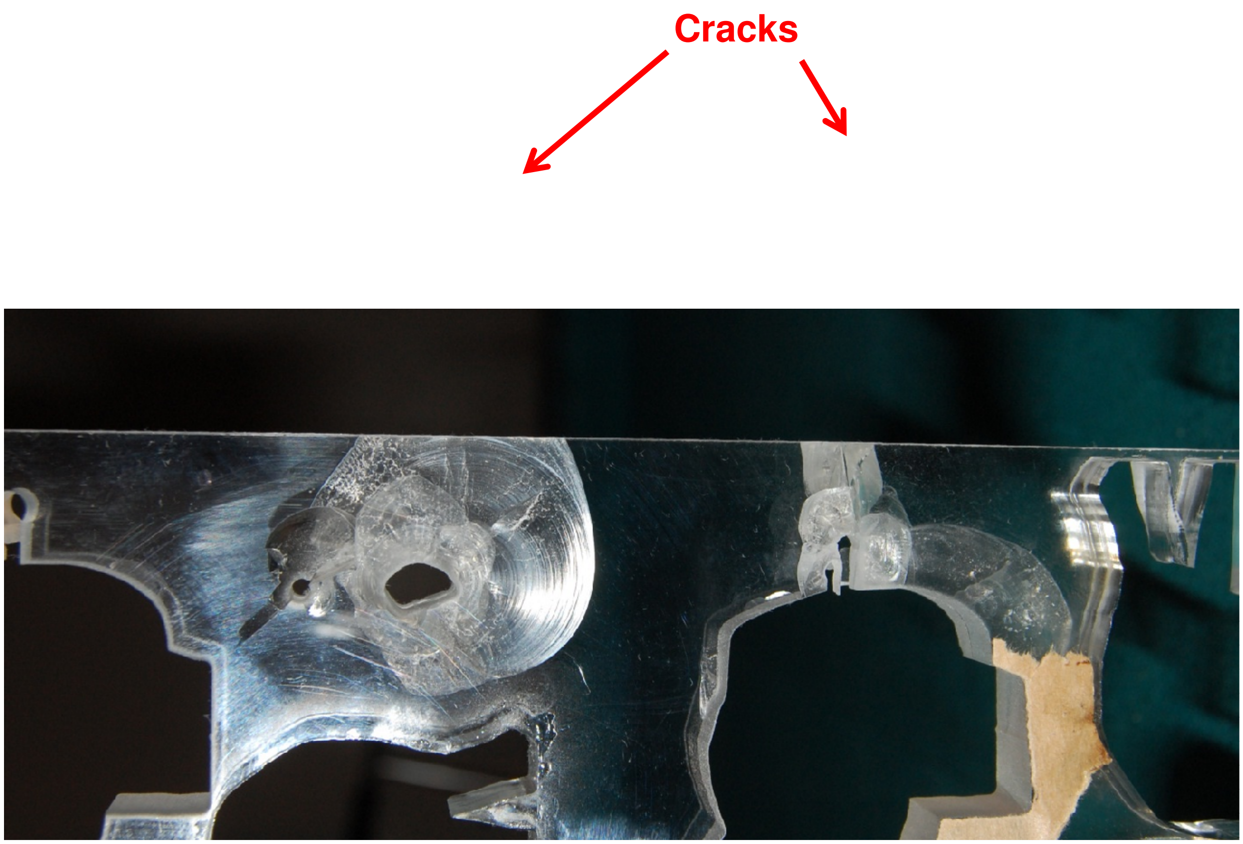


Figure 15. Cracked stock sheet of 3/8” acrylic due to water jet cutting.

This may have arisen from a combination of two attributes: the size of the animal and the intricacy of the animal shape. Upon inspecting the sheet the elephants were cut from, the cracks and unclean cuts were primarily concentrated for the child-sized elephant. Examining the diameter of the cut was 1/16” and relative to the height and width of the elephant there is a 0.0625:1.25 and 0.0625:1.75 ratio.

Because the water jet cutter is removing a substantial amount of material in relation to the overall size of the animal, the cutter may have applied a larger stress than the remainder of the material would withstand, resulting in cracking and failing. Along with the smaller size of the elephant, the intricate curvature of the elephant design could have contributed to the cracking. The initial design of the elephant was traced using splines, but after discussing with the manufacturer, we were instructed to only use straight line segments. In order to trace the curves of the sketch, many short line segments were needed to resemble the shape of the elephant. When water jet cutting the elephants, the short linear increments may have also caused the cutter difficulty and have contributed to the failure of cutting the acrylic.

After discussing with one of the Mustang '60 shop technicians, we were informed our acrylic sheet could be cut using their laser cutter. The laser cutting process proved to be a cost free, faster, and more effective way to shape the acrylic elephants in addition to our wood materials. Laser cutting the animals was a process of trial and error. Adjusting the power of the laser and its travel velocity controlled the depth of cut made into the material. This depth of cut dictated the number of passes required to cut to the other side of each material. If the power of the laser remained constant, but moved across the surface more quickly, this would yield a shallower depth of cut. However, if the power of the laser was too high or if the speed was too slow this caused the woods to burn and the acrylic to melt. A balance of the laser's power and speed was needed to avoid burning the woods or melting the acrylic. Another concern was the charring of a material. A high powered laser cut with a slow velocity burned the animals' edges and the smoke produced from the burning caused surface discoloration. Masking tape was needed to prevent the smoke from the burning to discolor the top surface of some of the animals.

Fabricating the rosewood crocodiles was more difficult than the other woods and the acrylic. The sample of rosewood was originally ½" thick and about 4" by 4" in size. The material needed to be planed down to 3/8", but because the size of the sample was so small and the material was highly dense the sample was kicked up every time a blade tooth struck the rosewood. Using a traditional planer proved to be an ineffective and unsafe method. This led to the use of a table top router to reduce the rosewood's thickness to approximately 3/8". However, the challenges did not stop there as the rosewood sample was just as difficult to cut as it was to plane. Cutting the rosewood was difficult because of the material's high density of 1.03 g/cm3. The laser was set to 100% power with a steady travel velocity of four. The next highest power setting was for the acrylic elephants at 80% power and a velocity of three. The laser cutter made eight passes over the crocodile shape and even though the laser cut to the other side of the wood, four of the animals could not be removed from the sample (Figure 16).

Figure 16. The laser cutter could not penetrate cleanly to the other side of the material. Left: the front, laser cut side and backside of the rosewood sample.

One of the crocodiles was removed using a box cutter, the remaining were unable to be separated from the stock because of attachments were still too strong. Less crocodile were manufactured for prototype testing because of this. This problem could be resolved by conducting one or two more passes with the same laser settings, or an alternate method of decreasing speed of the laser.

Durability

When developing an item that is to be used by young children, durability is always a concern. We needed to ensure the pieces to the Materials Safari Adventure were tough enough to survive the rigors of our users. The metals and polymers were of low concern because the materials and thicknesses selected made the animals inherently strong. Additionally, the rosewood and the oak showed no concerns of breaking during use of the kit. The balsa and alder crocodiles showed susceptibility to breaking during use. The reason for the breaking of the balsa was due to the material and the design. Balsa is a lightweight wood that is quite weak and can easily be broken by hand. The shape of the crocodile does not have the most durable design because certain sections of the animal have thin cross sections, making it weak structurally. To resolve the problem, the grain orientation was rotated 90° so that any stress would act more as a bending motion, which the balsa is more resilient against (Figure 17).

The clear varnish also added a support layer to the surface of the crocodile adding to its strength. Rotating the grain of the alder 90° also helped resolve the issue of breaking.

Figure 17. The grain orientation of the crocodiles was rotated 90 to help prevent breakage.

4.2 Child Development

Six Strands of Learning

The six strands of learning helped us design the kit to captivate audiences and portray information. Of the six strands, four were directly addressed in the kit: interest and motivation, understand scientific explanations, generate scientific evidence, and participate in scientific methods. In order to achieve the first strand of learning, multiple aspects of the kit were integrated into a safari theme to stimulate interest in the children. Materials samples were fabricated as safari animals, testing

stations were named and built to represent locations in a safari landscape, and a mat was included to portray the African landscape. Challenge cards aided in motivating the user by providing activities that require the user to mentally and physically engage with the testing stations. During prototype testing, the challenge cards were often useful to the facilitator for quickly posing questions to the children that could keep them interested and motivated by trying new scenarios. The facilitator also motivated the users by encouraging exploration of the materials and testing stations through the use of challenge cards and question-based guidance.

Understanding scientific explanations was another strand that we addressed in the kit. It became clear during prototyping that an important child development aspect to the kit that needs to be investigated is the language used to explain scientific concepts. The explanations offered had to refrain from using unfamiliar terms such as density and volume. Using words our user was unaccustomed to had the potential to embarrass the user and create a disconnect from the learning process. Adapting to the language that the children were familiar with was important to maintaining their attention and conveying the concepts effectively. The team experimented with using words like “More stuff is packed in this animal piece.”

Through interactions with testing stations and animal pieces, users generated their own scientific investigations and evidence. At the balance tree station evidence was generated to support a theory of density when children compared high density child size animals against low density adult sized animals. The mud pit station produced evidence for each interaction between wand and material. Often the child would expect the brass giraffe to be magnetic and discover that only the steel lion would stick to the want. The watering hole station provided evidence that the heaviest material did not always sink. The most effective example of this was when the children compared the light rosewood crocodile against the heavier large oak elephant. During testing children would be noticeably shocked to find the light little crocodile would sink while the heavier large elephant could float. The challenge cards also help to guide the user through generating evidence by posing questions and activities designed to provide evidence.

Users actively participate in scientific methods through interactions with testing stations as they explored concepts of weight, density, and magnetism. By holding certain variable constant and making predictions as to what would happen at the testing stations, users interacting with the kit were able to participate in the scientific method at an early age. The safari theme was especially important for attracting and maintaining motivation in the younger users of grades K-2 who would often engage with the kit in a free play fashion. Older users enjoyed the scientific methodology aspect of making hypotheses and generating evidence more.

Prototype testing revealed that two of the 6 Strands of Learning were not directly addressed in the kit because they were too advanced for our user’s age level (K-4): reflecting on science knowledge in society and developing an identity in science. Users didn’t display the ability to consider parallels between kit and society. Because they were more focused on direct involvement with the kit, they were not interested or ready to begin considering self-identity through science.

California Education Standards

To address appropriate educational topics for K-4 students, the kit incorporated the California educational standards for the physical sciences and the experimentation components. This was accomplished by developing testing stations to demonstrate the physical science concepts of weight, density, and magnetism. Testing stations and challenge cards promote learning of the differences in materials through physical interactions. Investigation and experimentation are integrated into the kit through the testing stations and challenge cards. Activities are presented in the challenge cards with the purpose of producing investigation and experimentation and reinforcing the concepts demonstrated at each testing station.

User Interactions

An effective exhibit for the K-4 ages must be able to portray both attracting power and staying power. The Materials Safari Adventure attracted users with the safari theme presentation. Displaying a fun atmosphere was an important aspect of whether a user would decide to interact with the kit. The kit was designed to captivate interest through the appearance of the animal pieces, testing stations, and unifying mat. Interest was sustained by applying challenge cards which encouraged interaction with the animal pieces and testing at each station.

Prototype testing also enabled us to establish our user's ability level and behavioral patterns. Using this information we were able to more efficiently tailor the kit to our user. We observed ages 5-6 years old portrayed short attention spans of 3 to 5 minutes. Knowing we had to demonstrate concepts under the restraints of a short attention span helped us modify our approach to maintaining attention and designing activities. The most effective teaching approach was to utilize Socratic methods to facilitate learning. Utilizing a question-based method produced longer interaction times with the testing stations. During prototype testing, through this method a user's interaction time increased to 17 minutes.

One activity we found in prototype testing that effectively demonstrated how materials are capable of behaving differently was to ask the user if the rosewood crocodile and balsa elephant would both sink, float, or behave differently. Continually the response was the elephant will sink because it was bigger, and the smaller crocodile will float. However, upon performing the experiment users observed the elephant floated and crocodile sank. This was a crucial moment in the thought process of our users as they instantly were taken back and wondered why this was the case. In this moment the facilitator had the important duty of effectively demonstrating the properties of density and volume.

The importance of the facilitator was realized by observing user interactions. We noticed 7-9 year olds enjoyed predicting and measuring properties, while 5-7 year olds preferred hands-on interactions. This information was used to help the facilitator personalize the learning approach to better suit the younger and older users. The facilitator is also crucial to maintaining and encouraging user interaction, and is necessary to mediate between fun and learning. Without a facilitator the user was only interested in having fun, and didn't always exhibit a shift to learning. The facilitator was necessary to provide

explanations of concepts portrayed at each testing station in a manner that was easily understood by the user.

Challenge cards were adapted to effectively guide the user through interactions based on observational analysis from prototype testing. We had difficulty applying certain cards with 5-6 year olds. Based off this information we created a difficulty scale for the challenge cards. Facilitator should select questions appropriate for user's age, otherwise more advanced questions would be presented to younger audiences. With help from Dr. Jipson from the Cal Poly Child Development department we revised the wording of questions to more clearly pose activities. Application oriented challenge questions were used to measure a level of understanding after interaction with each station. Most users were able to answer correctly to questions such as, "Which material is best for holding down a balloon?" and "What material should we use to build the frame of a kite?". This revision allowed users to understand the concept presented at that testing station.

5. Future Development

For future development, a key that matches pictures of the animal pieces with material information would be included to help the facilitator explain the materials science aspects of the kit. The key would enable any user or facilitator to clearly identify the material of any animal piece and then easily recognize relevant background information regarding that material. Also, answers to challenge cards should be supplied to help the facilitator explain the scientific concepts users will be demonstrating as they interact with the animal pieces and testing stations.

Dr. Jipson has expressed interest in taking over the development of the kit at the end of the quarter. With her connections and knowledge in child development, the Materials Safari Adventure can be further adapted to become the best possible teaching aid for K-4 students. She mentioned the possibility of allowing future child development students to take on the child development aspects of the kit for their senior project.

6. Conclusions

The Materials Safari Adventure was designed and developed to introduce audiences to a range of materials. Included in the kit are nine materials: 6061-T6 aluminum, a-36 mild steel, 360 alloy brass, clear cast acrylic, ABS plastic, rosewood, alder, balsa, and oak woods. The metals were water jet cut, the woods and acrylic were laser cut, and the acrylonitrile butadiene styrene (ABS) plastic was rapid prototyped. Testing stations demonstrate physical science concepts of weight, density, and magnetism. Prototype testing was conducted at the SLO Children's Museum and the Cal Poly child development lab. Through testing the safari theme was able to cultivate interest and motivation in users. The Materials Safari Adventure was able to successfully demonstrate and portray educational concepts presented at the testing stations, verified by the user's ability to correctly answer application driven questions.

7. References

1. *Science Content Standards for California Public Schools*. California State Board of Education, 11 June 2009. PDF.

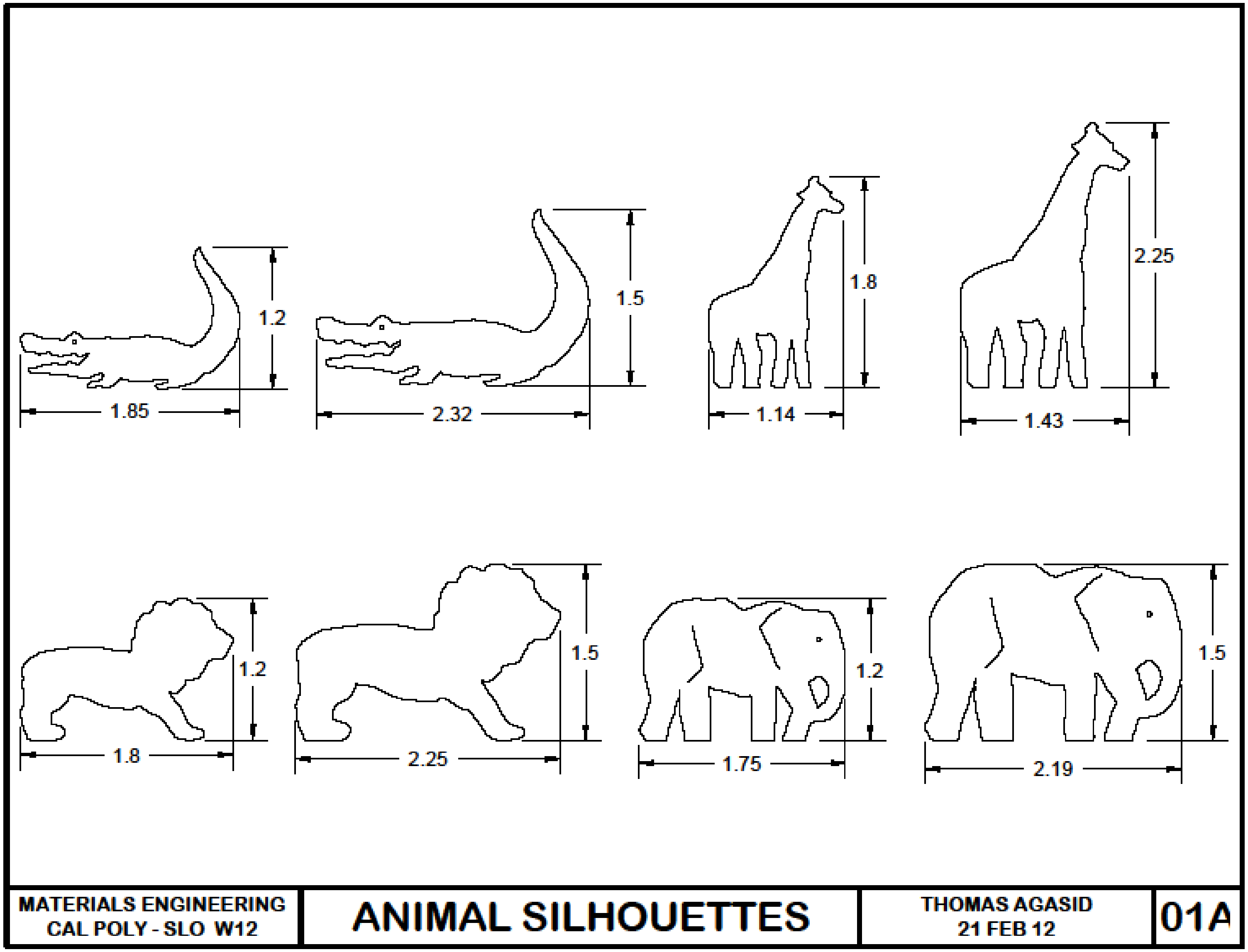
2. Bell, Philip. *Learning Science in Informal Environments: People, Places, and Pursuits*. Washington, D.C.: National Academies, 2009. Print.

3. Kloos, Heidi. "Interlinking Physical Beliefs: Children's Bias towards Logical Congruence." (2006). *Www.sciencedirect.com*. Web. 20 May 2012.

4. Falk, John H., Elizabeth Donovan, and Rosalie Woods. *Free-choice Science Education: How We Learn Science outside of School*. New York: Teachers College, 2001. Print.

5. *Guidelines for Exhibit Production*. San Luis Obispo: San Luis Obispo Children's Museum, 21 Oct. 2011. PDF.

Appendix A: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