UNIVERSITY OF WISCONSIN-MADISON
DEPARTMENT OF BIOMEDICAL ENGINEERING
BME 200/300 DESIGN

Reaction Time Measurement Device

Final Report

Clayton Lepak-BWIG
Darren Klaty-Communicator
Hope Marshall-BSAC
Nathan Retzlaff-Leader

Advisor: Pablo Irarrazaval Mena

Client: Dr. Tom Yin
UW Madison Department of Physiology

12/8/2010

Abstract

In the case of simple reaction times, auditory stimuli yield faster reaction times than visual stimuli. This is a significant phenomenon when considering life-threatening situations such as automobile accidents. Though the reaction times only vary slightly, the response to hearing a screeching car is essentially faster than observing the brake lights activate. A device is desired which can demonstrate this reaction-time phenomenon in a classroom setting for school children in grades 1-8. There is a desire to get young students involved in math, physics, and science at a younger age- particularly in the Madison school district with the recent passing of an outreach program connecting the Madison schools with the University of Wisconsin. Such a device could excite students in all of these subject areas. However, no such device is currently readily available on the market. Based upon a set of guidelines and requirements compiled for the device with Dr. Tom Yin of the UW-Dept. of Physiology, four specific, well-developed design alternatives were created by the design team. The designs were evaluated in a design matrix to decide upon the Rube Goldberg design as the final design. Fabrication was split into developing the mechanical Rube Goldberg components and building the electronic program powered by Arduino to functionally operate the device. The two components were then combined to give the functional device. Upon testing the final device, a sample size of 100 trials of both auditory and visual reaction times proved that auditory reaction indeed was quicker.

Table of Contents

Problem Statement

A device is desired that will measure and compare simple visual and auditory reaction times in order to demonstrate the difference between audio and visual processing times. The final device will be used primarily in educational classroom settings for children grades 1-8 as a means to generate excitement about physics and science. The device must be intriguing and intuitive for its target audience. There is also the potential to incorporate other sensory reaction times into the device.

Background and Motivation

Reaction time measurement is a fairly self-explanatory study: that of measuring the time it takes for a subject to react to some sort of stimulus. Whether a sports athlete is trying to boost performance times or someone is commuting to work, reacting to stimuli is a part of daily life. There are four types of reaction times commonly studied. *Simple* reaction time is a response time for a test subject to respond to the presence of a stimulus such as a light or sound. *Go/No-Go* reaction time refers to the required time for a subject to respond to one stimulus or withhold from responding to a different stimulus type (i.e. it involves a decision of hitting a button for one stimulus while not hitting it for another stimulus). *Choice* reaction time measures how long it takes for a subject to generate a distinct response for a distinct stimulus (example: push button 1 when one stimulus appears but push button 2 if the other stimulus appears). *Discrimination* reaction time measures response time for comparing pairs of simultaneous stimuli and distinguishing a certain difference (example: hitting button one or two based upon which stimulus was brighter/louder). A high degree of variability can be found within given trials for an individual due to their level of mental focus. Reaction time also varies from person to person due to genetic and environmental factors [1].

Simple reaction time has been studied extensively for quite some time. It has been shown that reaction times to visual stimuli are slower than reactions to auditory stimuli [2]. Many studies have confirmed this phenomenon over time. The reason for the faster auditory reaction time has also been studied. It takes 8-10 milliseconds for an auditory stimulus signal to reach the brain [3] whereas a visual stimulus signal takes 20-40 milliseconds [4]. In a study of healthy college aged individuals, an auditory stimulus generated an average reaction time of 160 milliseconds whereas the visual stimulus yielded an average reaction time of 190 milliseconds [5]. These are the reaction time values that have been widely accepted throughout the science community. However, modern online reaction time tests often yield slower results in part due to a delay in electrical programming of the software [6]. This difference has also been shown in research by Eckner, et al studying NCAA football players who averaged a 203 millisecond reaction time to a falling meter stick but 268 milliseconds for a visual stimulus computer test [7].

The research of Dr. Tom Yin-the client for this project-has yielded additional reasoning to the stimuli dependent reaction time phenomena. Yin has explained to the team that visual stimuli require signal amplification as well as a chemically gated cascade in order for processing to occur. Conversely, the auditory stimuli propagate quickly via hair cells basked in fluid and open mechanically gated ion channels which allow shorter duration to send the signal. Ultimately, he explains that a tradeoff exists between the sensitivity and signaling speed of the auditory and visual systems of the human [8]. The more sensitive visual system requires slower processing speeds than the less sensitive auditory system. Dr. Yin has expressed an interest in demonstrating this reaction time data research in classroom settings as an initiative to get children interested in physics and science.

Currently there isn't a manufactured device to demonstrate the variation in reaction times for auditory and visual stimuli. The client's desire to create such a device arose from a visit to the Chicago

Museum of Science and Industry where a simple reaction time test is performed for visual or auditory stimuli via a falling ruler held by an electromagnet. The desired device would be used heavily in outreach applications for students in grades 1-8 (ages 6-14) in local area schools as a demonstrative tool. The Madison Area School Boards have added, as part of the middle school curriculum, a requirement for hands-on scientific experiences involving the human body. Dr. Yin has seen this requirement as a prime opportunity to utilize such a device which would demonstrate a cognitive phenomenon and get students thinking about science.

Research has shown that for mathematical and science education, students in grades 2-8 learn best when given the opportunity for "interactive, hands-on, play-based" learning as is evident by the vastly growing number of children's museums nationwide [9]. Therefore, as a critical aspect of a functional reaction time measurement device, an entirely "hands-on" learning approach will need to be considered.

Design Constraints

Due to the nature of the project as a demonstrative tool in an educational environment, the design is accommodating in a lot of aspects. However, the team must still adhere to some preset guidelines. The budget for the device is $200 which includes all materials, fabrication, testing, ect. Additionally, the final device must be easily transportable in the back hatch of a standard minivan. An overall mass of 20 kg should not be exceeded. The setup/teardown of the demonstration should not exceed 10 minutes. The device must incorporate a test of simple reaction times to audio vs. visual stimuli, although additional senses can be incorporated. Further opportunity exists in the potential to incorporate variations in the intensity level of the stimuli. The final device must accurately measure the auditory and visual simple reaction times, and thereby demonstrate faster auditory reaction times as per the literature. It's also critical that the final design is visually appealing so as to draw attention of children and add to the hands-on learning experience. Safety is a concern of the design which must be anticipated so as to avoid any potential issues with electrical and mechanical components.

Design Alternatives

In order to ensure that the final device would truly appeal to the target audience in an educational setting, the team developed a wide variety of creative ideas that could be incorporated into reaction time measurements. A LASER (Light Amplification by Stimulated Emission of Radiation) design portrays a valuable gem protected by a security system. The test subject would be asked to “react” to either security lasers briefly turning off (visual) or a sound system activating (audio). A second ruler design would simply drop a ruler hung by an electromagnet while simultaneously sounding a buzzer or lighting a light bulb. A third design uses a toy ambulance which would be modified to choose between sounding its siren, lighting the flashing lights, or both. The subject would be asked to slam on the brakes to react to the stimuli. Finally, the fourth alternative (and the one which was pursued), involves a marble rolling through a Rube Goldberg system. The marble passes a motion sensor which begins timing the reaction while simultaneously activating the desired stimuli. A subject simply depresses a button to react to the stimulus before the marble falls through a trapdoor mechanism.

LASER Design

The Laser reaction time design would be set up as a game geared towards children ages 8-14. The device would be approximately 2 feet by 2 feet and would include a green laser, mirrors, an infrared sensor, a toy diamond, a hand placement cutout that looks like a security system hand scanner, very thin posts about 6 inches tall, a switchboard and a display timer as shown in Figure 1. The toy jewel would be placed in the middle of the setup while the laser beams, created by one green laser and 5 adjustable mirrors on posts, would surround it, as if it were an expensive artifact at a museum. The hand placement cutout would be placed where the subject positions his or her hand at the start of the trial.

The object of the trial would be for the subject to react as quickly as possible to either the laser security system turning off, or to the indicated stimulating beeping noise, and to reach for the jewel at that time. The infrared sensor would be located parallel to, and very close to, the laser beam closest to the hand placement cutout and would span the plane that a hand could move through when reaching for the jewel. The security system laser turning off is the visual stimulus and a beeping noise is the auditory stimulus. The stimulus would start the timer and the hand breaking the infrared sensor beam would stop the timer.

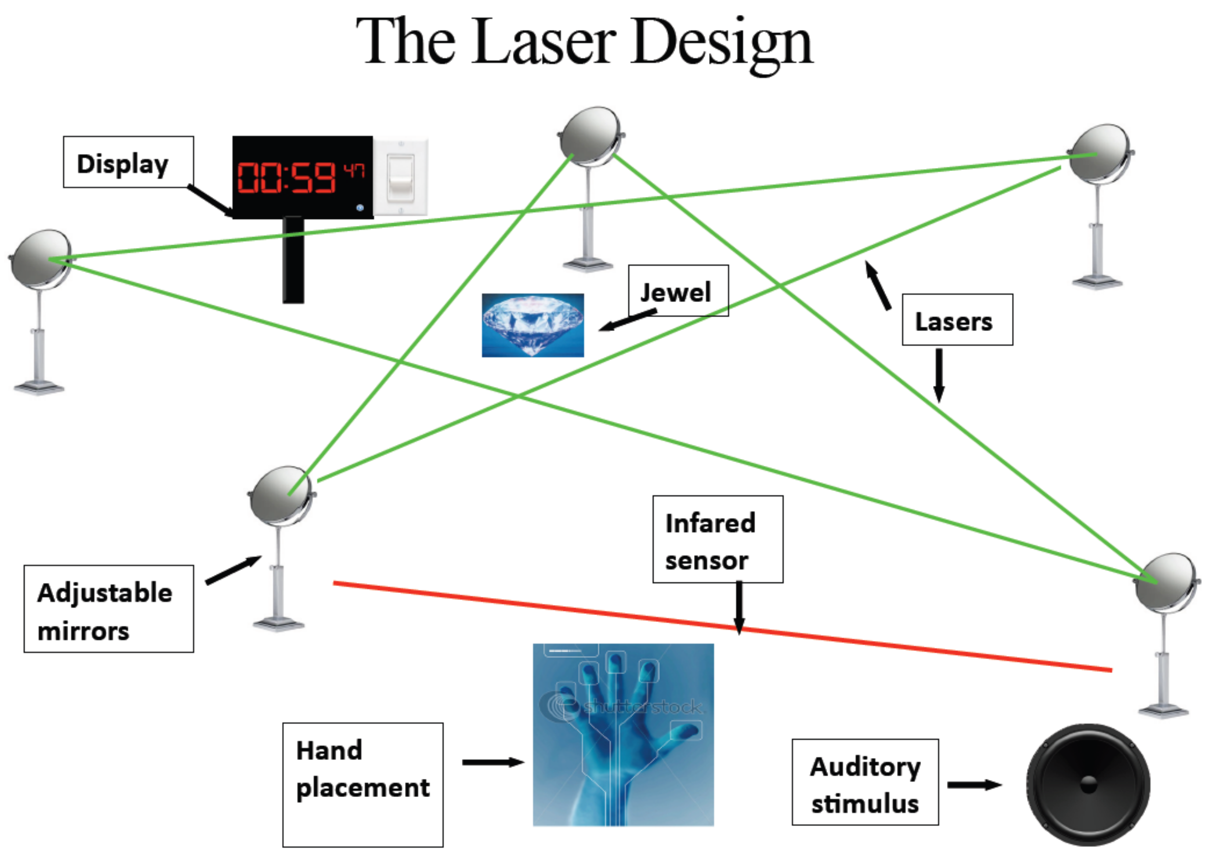

Figure 1: Diagram of the Laser Design Alternative. A test subject places their hand in the placement frame and waits until the LASERS deactivate (visual stimulus) and/or the auditory stimulus activates (signaling a trip in a security system) at which time they reach to grab the jewel placed inside the lasers. An infrared sensor is used to detect when the hand crossed the plane in reference to the activation of the stimuli.

The reaction time would then be displayed on the LED display timer. It would be explained to the subject that if he or she reacts quickly enough, he or she could obtain the jewel without the security system coming back on. This would motivate the subject to react as quickly possible. The adult administering the trial would have control over whether the stimulus would be an auditory stimulus (beeping sound), a visual stimulus (the security system lasers turning off) or both, by using the switch.

The advantages of the laser design include that lasers are visually appealing and fun for kids of all ages. The design would be straightforward and simple and the subject would have strong motivation to react quickly. The visual feedback for this design would be quite satisfying as the design relates to a real-life security system. Cost would be a slight advantage, since the laser design would be cheaper than 2 other designs. Also, since the laser design would be game board sized, the device would be easy to transport, store and set up. The device would depend on batteries and another power source, which are relatively reliable. Also, the device would be easy to manufacture.

Disadvantages of the design include that even with a green laser, the laser beams may be hard to see in a well-lit classroom. Also, there is a safety factor with the lasers that hasn't been well evaluated and therefore, the design could be potentially harmful. Small children may not understand the security system game without an adult carefully explaining it to them. They also might not be able to relate the game to anything that they are familiar with. Another major disadvantage of the laser system is the fact that there would be no direct physics correlation of distance as it relates to reaction time, which is one of the main qualities of a successful design. A final disadvantage is that the device would indirectly promote stealing. Therefore, stealing a jewel, or beating a security system would be a bad theme for the target audience.

Ruler Design

The ruler design alternative would include a wooden frame for the system (made out of 2x4 lumber), a circuit board, which would include a battery and a switch, a special glove with metal tips, an LED display, a meter stick, an electromagnet with a hook that would hold up the meter stick, a speaker that would provide the auditory stimulus and a light bulb that would provide the visual stimulus as seen in Figure 2. The ruler would drop as the stimulus occurred and the user would attempt to catch the ruler as quickly as possible to measure reaction time. The battery would supply power for the light bulb, the speaker, and the electromagnet. The glove with metal tips that would be wired to the circuit board, would be worn by the user so that at the instant the user catches the conductive meter stick, a circuit would be completed and the timer, which would be started as the stimulus occurred, would stop. The reaction time would then be displayed on the LED timer. The adult proctoring the use of the device would decide which type of stimulus to use by using the switch.

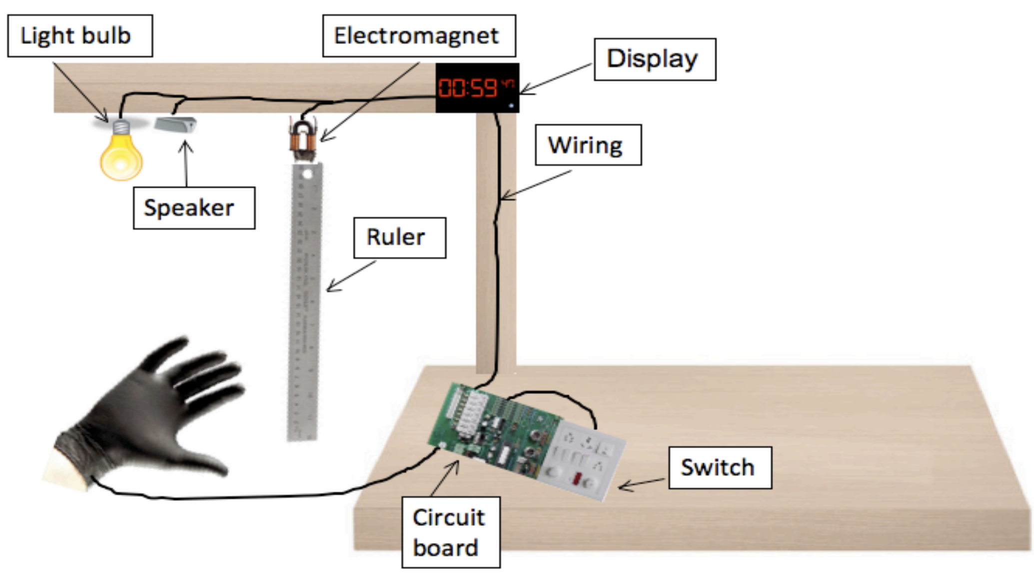

Figure 2: The ruler design alternative including a table it would be set on. Essentially, the device holds a conductive ruler vertically with an electromagnet. The electromagnet releases the ruler at a randomized time while simultaneously activating the desired stimuli and starting the timer. The subject is wearing a glove with conductive pads so that when they squeeze to catch the falling ruler, the circuit is shorter triggering the stop of the timer. The reaction time is therefore displayed on the screen.

Advantages of the ruler design include the direct physics correlation. Reaction time could be directly measured based on the distance the ruler fell using constant acceleration due to gravity. Also, the ruler design would be quite reliable.

Disadvantages include the lack of appeal of the ruler design. When compared to the other design alternatives, the ruler design would be the least amusing. Also, ease of transport and cost are weak points of the ruler design alternative.

Ambulance Design

Another design would model a real-life intersection that an individual on a bike might encounter. The design would be built around a toy ambulance outfitted with a siren and flashing lights. This ambulance would be placed in a mock intersection in front of the participant. In front of the participant there would also be a set of bicycle handlebars outfitted with handbrakes. The handbrakes would be hardwired to stop a timer upon depression of the brake. The person controlling the demonstration would have three potential buttons to press: one to sound the siren, one to activate the lights, and one to activate both stimuli. All of the buttons simultaneously would start the respective timer on the scoreboard time display. The participant would squeeze the handbrakes as soon as they hear the siren or see the flashing lights, which would stop the timer. Once stopped, the reaction times would be presented on the scoreboard so the user could compare their

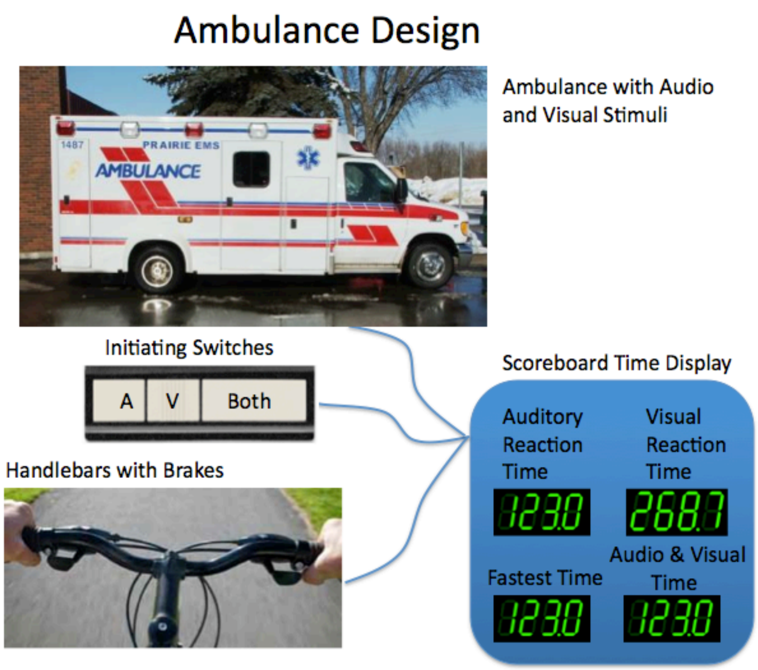

Figure 3: Diagram of the Ambulance design alternative. A toy ambulance is rigged up to allow activation of the siren, lights, or both simultaneously. The subject holds onto bicycle handlebars (as if they were riding a bike) and is asked to react (brake) as fast as possible upon activation of the stimuli. The reaction times are then projected to a scoreboard.

different reaction time scores and see which reaction method is fastest. This is shown in Figure 3. The life-like situation would help get participants involved with the test and would provide motivation.

Even though the subject may be motivated to perform well there would be no direct physics correlation with this design. Despite this, the ambulance would be the simplest, cheapest, and most durable alternative. The only components that would be repeatedly used (the button and the handbrakes) are both designed for repetitive use and are thus unlikely to break. Also the small compact design allows it to be easily transported without any risk of breaking.

Rube Goldberg Design

The final design alternative is a version of a Rube Goldberg machine. As the most creative and visually appealing design, this alternative would likely grab significant attention and interest. The machine can be best understood by grouping the components into two main parts: the reaction process and the user feedback.

The reaction process starts with a line of marbles waiting to be released down a chute. As each marble is released, they enter free fall past a motion sensor en route to a funnel ready to catch them. When the motion sensor detects the marbles dropping

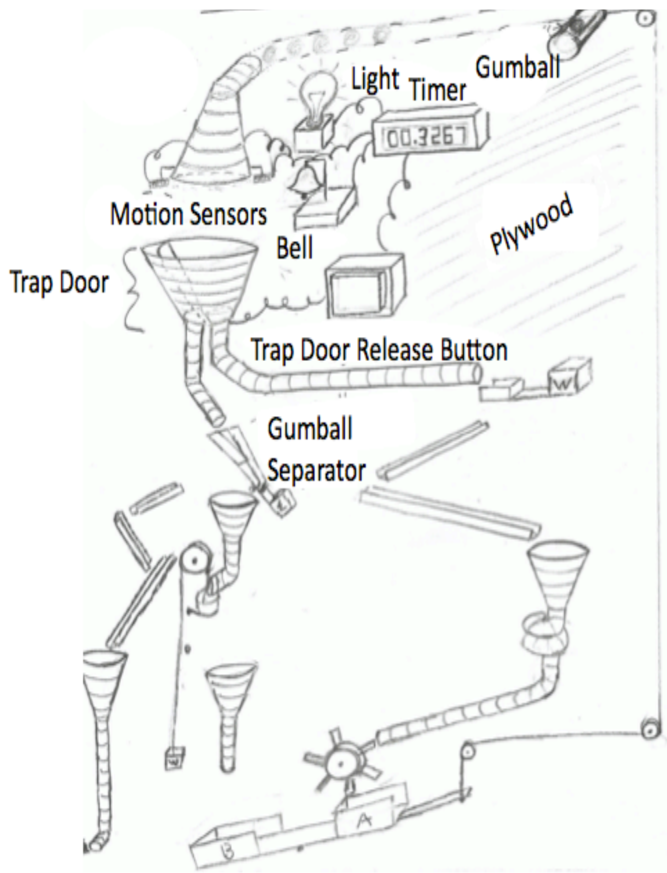

Figure 4: The Rube Goldberg design alternative. A marble rolls silently through a motion sensor to activate the stimuli and start the timer. The test subject is asked to press a button attached to a trapdoor mechanism. If they react fast enough, the marble is rerouted to a "winning" path. Otherwise the marble travels the "failed" path. When enough fast reactions have been made, a scale tips to release a gumball to the subject as an incentive to try to react fastest to both stimuli.

through its field of vision it either rings a bell, flashes a light, or both while simultaneously starting a digital timer. When the individual using the device detects the stimuli they are to press a stop button for the timer as fast as possible. When this button is pressed the timer stops and the time is displayed on the digital screen. This also opens a trap door in the funnel sending the marbles down a series of mechanisms before being deposited into a box on a fulcrum. When the participant gets enough marbles into the right side of the balance, it tips the seesaw and applies tension to a rope attached to its side. This rope ultimately releases a gumball into the system. The gumball then rolls to the marble release mechanism and drops through the chute and past the motion sensor.

When the participant sees the gumball dropping from the chute they would be expected to refrain from pressing the button. This would allow the gumball to follow a separate path down to the user. The gumball would act to motivate subjects to perform their best with the experiment. The downside of this project would be the cost and structural instability. Because the project would be unstable and would have gaps between its components, all components would need to be attached to plywood.

Design Matrix

The design matrix was split into 6 different categories: manufacturability, transportability, cost, physics correlation, age-appropriateness and reliability. The breakdown of the available points in each category is illustrated in Figure 5. The first three categories to be discussed only represent 20% of the total points. Manufacturability, the first and smallest category, is a measure of the ease of fabrication. This category was not given much weight due to the fact that the fabrication process for each design was not thought to be excessively difficult. The problem addressed by this design project is not very

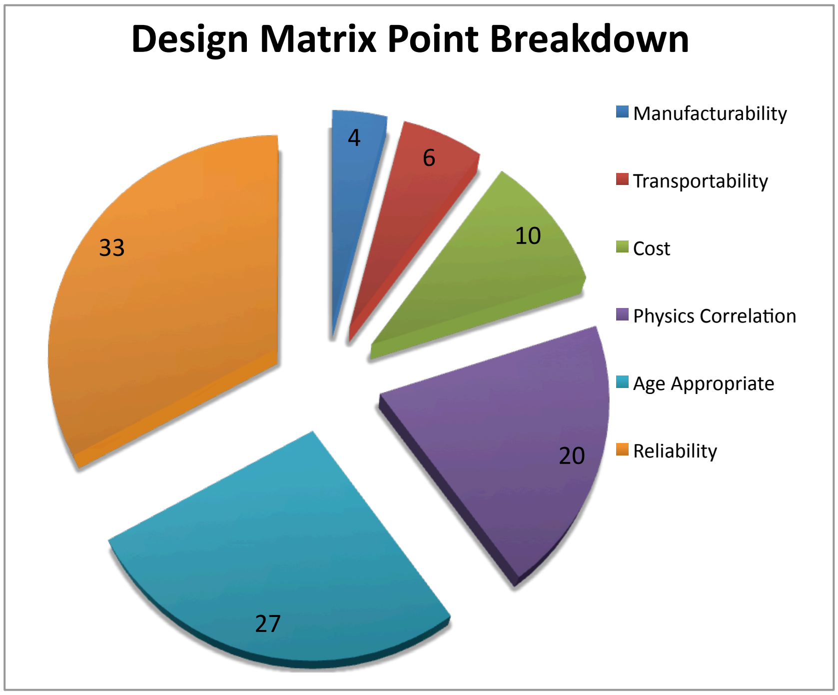

Figure 5: Point breakdown for the design matrix. Notice that clearly the reliability, age appropriateness, and physics correlation are clearly the most important factors of a successful design. These criteria were used to evaluate the proposed solutions to therefore pursue what the team deemed the most effective solution.

technical, and therefore any fabrication that will be needed should fall easily within the team's capabilities.

Transportability was also given a small point value. Although the client stressed the need for the design to be transportable by one person, and fit easily in the back of a van, these minimum specifications were thought to be easily attainable. For this reason, any further advantages in terms of transportability, while practical, were not highly valued.

The last of the three smaller categories is cost. The team was given a maximum budget of $200 to work with. While spending less money may be preferable, the team should not sacrifice other important aspects of the project in order to stay well under the budget. As long as the design stays under $200, preference should be given to the categories that work to address the problem statement.

A table of the points awarded to each design in every category is shown in the design matrix below (Table 1). As illustrated, the ambulance design does very well in the first three categories. This is due to the fact that this design is relatively simple and has few parts. The Rube Goldberg design on the other hand struggles. It is the most complicated design, and with its vast amount of interacting parts, it would be by far the hardest to manufacture. Its size and number of parts make it costly and difficult to transport. The other two designs score moderately in these categories. They lose points for the same reason as the Rube Goldberg, though in smaller amounts.

Physics correlation is an evaluation of how intuitive each design is. Since the purpose of the project is outreach in a middle or elementary school setting, it is essential for students to have an understanding of what is going on. The design should encourage independent thought and introduce basic physics concepts. Both the Ruler and the Rube Goldberg do very well in this category due to their moving components. With both designs the students can be encouraged to draw the connection between the movement of the falling component and reaction time. The Laser and Ambulance lack any moving component and therefore do not score many points in this category.

Category	Total Points	Rube Goldberg	Ruler	Laser	Ambulance
Manufacturability	4	2	3	3	4
Transportability	6	2	4	5	6
Cost	10	4	7	7	10
Physics Correlation	20	18	20	7	5
Age Appropriate	27	27	10	25	20
Reliability	33	24	29	26	31
Total	100	77	73	73	76

Table 1: Design matrix of the product shows that all four design alternatives had potential to solve the problem at hand. However, the team deemed the Rube Goldbert design as the one which could best fit the many requirements of the design.

Age appropriateness is an indication of how well each design captures and holds the attention of elementary and middle school students. Since the intent of this design is solely for outreach, it is essential that any proposed design have the quality of being fascinating for the target audience. Only if the device is intriguing will the client be able to teach his lesson before a receptive audience. For this reason, both the Laser and the Rube Goldberg dominate this category. Both would be highly interesting, challenging, and rewarding to children in the target age group. By offering strong positive feedback for quick times, both encourage students to focus on doing their best. The Ruler design suffers the most in this category. Although it may be appropriate for an older, more scientific audience, it would seem boring to children in the target age group.

Reliability is the largest category in the design matrix. This is a result of the client's emphasis for a design that could be taken anywhere, set up, and work properly. It is also essential that the design give consistent results showing that auditory reaction time is faster than visual. Due to the number of parts in the Rube Goldberg design, and the potential inconsistency in the way the reaction time will be measured, it loses reliability points. The ambulance, being a very simple design with an accurate way to calculate reaction times, scores very well in this category.

The final point breakdown is shown in Figure 6. Although the Rube Goldberg did score the most points, the difference between the highest and lowest score was only four. This illustrates the uniqueness of the project. Unlike most other design projects in the course, this project is not very technical. For this reason, a lot of emphasis was placed on the brainstorming process in order to come up with the best, most unique designs possible. This resulted in four thoroughly developed designs, each of which could have adequately addressed the problem statement. This is represented by the small difference in total points.

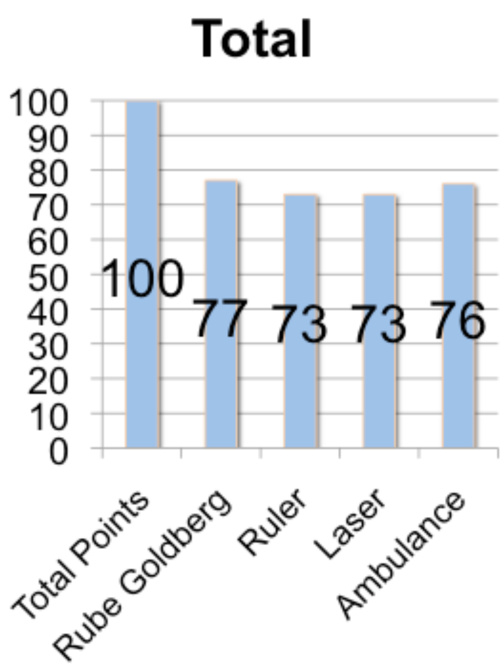

Figure 6: Final points for alternative designs. Despite the lack of a clearly dominant design alternative, the team deemed the Rube Goldberg design as the final design since it poses huge potential to be fit the constraints of the device.

Although the design matrix does not provide compelling support for the Rube Goldberg design, the team does feel that it will be the best choice to move forward with. The Rube Goldberg has tremendous potential in terms of originality and innovation. The excitement that will be inherent with it will make every child want to test it out. Though other designs are viable options, compared to the Rube Goldberg, they lack the creativity and excitement that will make the Rube Goldberg design great.

Fabrication

Mechanical Components

The fabrication of the mechanical components of the design consisted of fabricating the overall display and supports, the trap door mechanism, the release mechanism, and the feedback components of the Rube Goldberg design on the lower half of the display. To fabricate the display, a 4'x 8' piece of plywood was cut into six sections, four of which are held together by hinges to form a stable display. A 1.5'x 3' piece of plywood forms the top piece of the display as shown in Figure 7. To support the structure, both sides of the frame are supported by two 2'x 4's. For the 3' tall side of the display, each of the 2'x 4's are attached to the plywood by a bolt and there is a sliding mechanism that allows the supports to fold against the plywood for transportation and storage. For the 6' tall side of the display, the 2'x 4's are also attached to the plywood using bolts. Since this side of the display folds down, the 2' x 4' supports are designed so that they fold down as well.

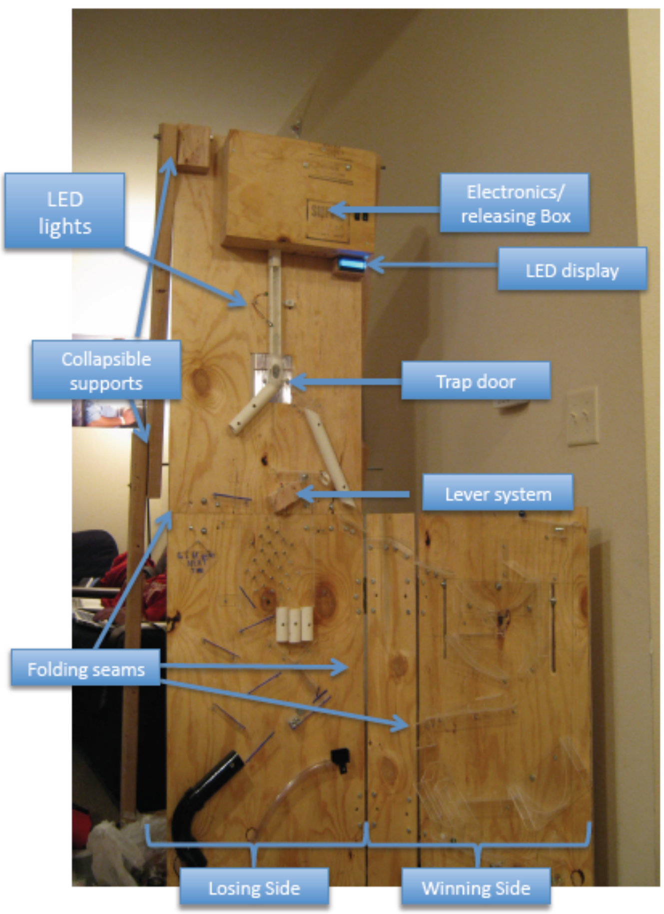

Figure 7: Schematic diagram with all components labeled when device is standing.

The release mechanism, shown in Figure 8, is designed to slow down the marble silently so that the participants cannot predict when the marble will be released to begin a trial. This was accomplished by constructing two acrylic half pipes. A hole was placed in the middle of each half pipe so that when the marble slows down, it falls out the hole. The two half pipes were configured so that a marble placed in the upper half pipe will fall into the lower half pipe when it slows down sufficiently. The marble then rolls back and forth in the second half pipe until sufficiently slowed; at which point it falls out of the second hole and down a 1 " PVC pipe. Paper was used to line the acrylic in order to dampen the sound and ensure that the test subject couldn't anticipate the marble dropping. The acrylic was cut and solvated together to ensure a strong lasting bond. The releasing mechanism was then bolted to the inside of the box used to conceal the mechanism and the electronics portion. The client, standing behind the display, will place a marble in the releasing mechanism with an option to release the marble into the upper or lower half pipe for increased variability. The marble will then spend an unpredictable amount of time in the mechanism, fall down the PVC pipe and past the sensor, triggering the stimuli, and continue down to the trapdoor mechanism.

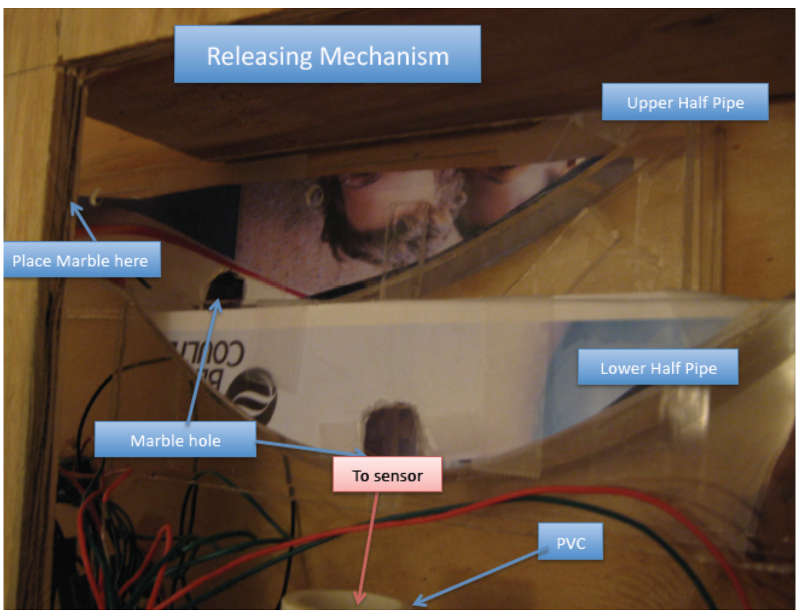

Figure 8: This shows the releasing mechanism for the final prototype. This box is not visible to the user and houses the releasing mechanism (the upper and lower half pipes), as well as the electronics. Additionally, the PVC tube containing the IR motion sensors begins in this portion of the structure.

The trap door mechanism, shown in Figure 9, is designed to divert the marble to either the "winning" side of the Rube Goldberg display (right side) or the "losing" side of the Rube Goldberg display (left side) based on calculations that indicate the distance that the marble would drop in 0.2 seconds (which would mark a "winning" reaction time). Based on the calculations regarding freefall, the marble will drop 13 inches in 0.2 seconds, which was therefore used as the distance between the release mechanism and the trap door mechanism.

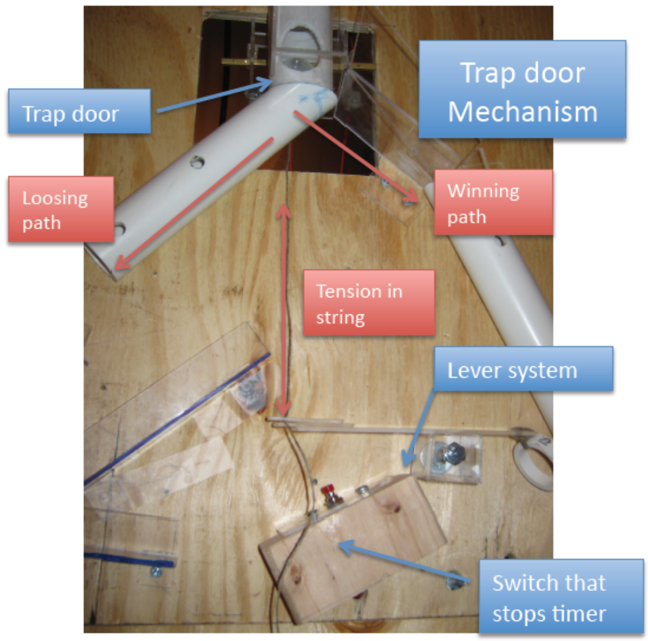

Figure 9: Trapdoor mechanism for the final prototype. The marble falls to the left (losing) side if the lever system is not depressed before the marble arrives at the trapdoor. When the lever is pushed, it shorts the circuit by hitting the switch which ultimately stops the reaction timer. The right path is the winning path for when the lever system is pushed before the ball arrives at the trapdoor.

The trap door mechanism was fabricated using 1.5" diameter PVC, 2" diameter PVC, a small brass rod, a washer, Plexiglas, two 0.25'' nuts, and an A-40 size nut and bolt. To build the trap door, a small hole was drilled into a 0.75" diameter washer, which was then tapped, and the same side hole was drilled into the center of the hollow brass rod. The small nut and bolt connected these two components together. Two holes the same size as the brass rod's diameter were drilled into the large PVC and the brass rod was slid through the holes so that the brass rod can rotate freely. A hole was drilled in the PVC large enough to allow for the diversion of a falling marble to the "winning" route. When the washer is in a vertical position, which is the default position, the marble falls straight through the large PVC tube, which is the "losing" route. To rotate the brass rod and thus change the position of the trap door inside the PVC, a string is connected to a pair of acrylic arms which when pulled apply a moment on the brass rod. The string is attached to a lever system which when pressed down, activates the switch to stop the timer, and pulls the string down diverting the marble to the winning side.

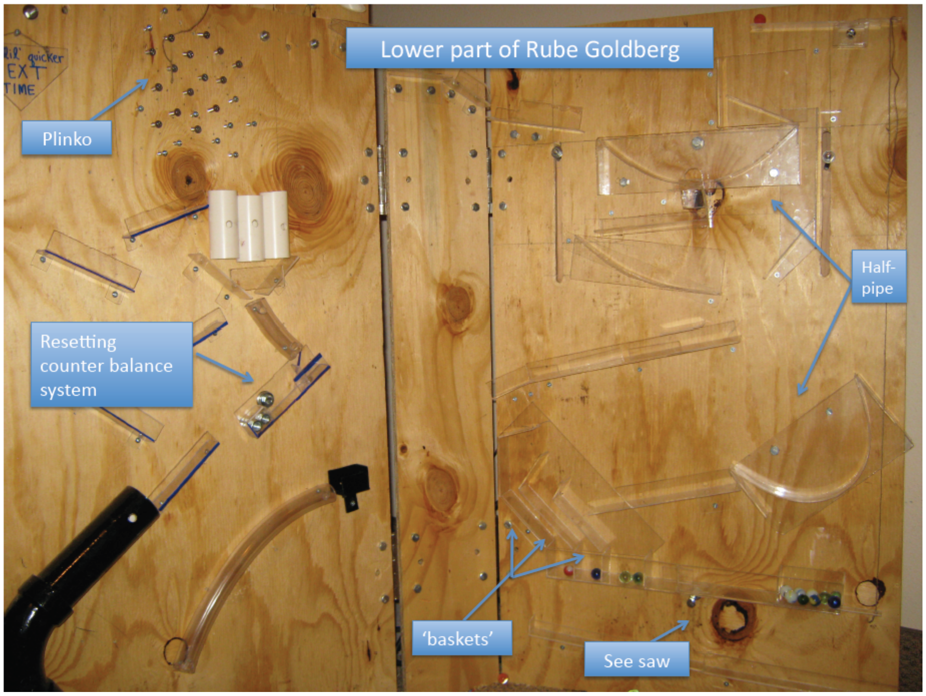

Figure 10: The lower part of the Rube Goldberg design with all of the feedback components.

The lower parts of the Rube Goldberg design, which are shown in Figure 10, (the "winning" and "losing" side) were fabricated using acrylic, string, PVC, and wood screws. The winning side crosses over the folding gap via tiered acrylic pathways. This leads to a half pipe (the same concept used in the releasing mechanism), which then drops the marble down two ramps, launching the marble across a gap. The marble is launched into another semicircular ramp that reverses the marble's direction and launches it towards three 'baskets' placed at different heights. The three baskets lead down to boxes on a see saw. The highest basket leads to a position furthest from the fulcrum, the lowest to a position closest to the fulcrum, and the middle to one in the middle of the highest and lowest positions. This causes a marble that has a good launch to affect the see saw the most (it will have the largest moment), and a bad launch to affect it the least. Once enough marbles go down the winning side to outweigh the counter balance (a box on the other side of the fulcrum containing a variable amount of marbles), the see saw tips. This releases tension on a string acting to counter balance a 'winning marble' back at the top of the plywood. This marble is then released and falls through a series of ramps, jumps the folding gap, and lands in the "You Win!" box. This signals the end of the trial. At this point the marbles in the see saw must be emptied to the track below it that leads to the side of the device where a cup can collect them. Also the winning marble must be reset.

The losing side leads to a Plinko, which randomly diverts the marble to the left track or right track. The left track lets the marble fall down a series of acrylic tracks and finally into the ending box. The right side funnels the marble into a resetting counter balance system, which rotates and lets the marble fall into a tube that leads to the ending box. This box is one of the three things that need to be reset after each session.

Electronic Components

The electronic portion of the design involved some extensive circuitry for an otherwise rather simple design. The timing device is powered and operated by an Arduino Uno Atmega328 microcontroller. This microcontroller can be powered via USB connection to computer or an AC wall outlet adapter. The code (which can be found in the Appendix), was written by the team to run individual trials as required by the design. The Arduino code can be easily changed and re-uploaded to the board if changes become necessary. Fabrication began with the basics, slowly adding hardware and building up to the more complex components. First the LED's and buzzer were wired up with simple code to turn them on and off using the digital pins on the Arduino board. Switches were then installed to control whether the LED's, the buzzer, or both were turned on. Moving on from the LED's and buzzer, the infrared emitter and detector (which serve as a motion sensor for a falling marble) were next. The IR detector senses a drop in voltage when the IR beam (from the emitter) is blocked (as by a falling marble) [10]. Through testing we discovered that the infrared detector is sensitive to background light in the room but aiming the detector and emitter directly at each other and encasing them in a tube that funnels the light from the emitter directly at the detector can overcome this. Through analysis it was found that the threshold voltage change that would accurately detect a passing marble was 390 mV. This threshold was constantly adapted to accommodate the desired function of these hardware components. Circuitry was initially built on a standard breadboard to allow for easier troubleshooting and rearrangement before all components were soldered and mounted on the final prototype. Upon successfully building the circuitry and code to sense the falling marble and activate an auditory (mini 12 V DC buzzer) and/or visual (set of LEDs) stimuli, the team focused on incorporating a timer which could be stopped by subject input (stop button) and later displayed on a screen [11].

Although a 4-digit 7-segment Serial LED display had been purchased because of its advantage of simple wiring (only 3 required wire inputs), the coding was written in HEX programming language and didn't allow for sufficient compatibility and usability. Therefore, the team instead acquired a 16-row x 2-column LCD backlit display. Although the connections required to power and use this hardware are significantly more complex than the 3 wires required for the serial display (as seen in Figures 11 and 12) the LCD display easily reads strings of code as input in layman's terms and displays them directly onto the screen.

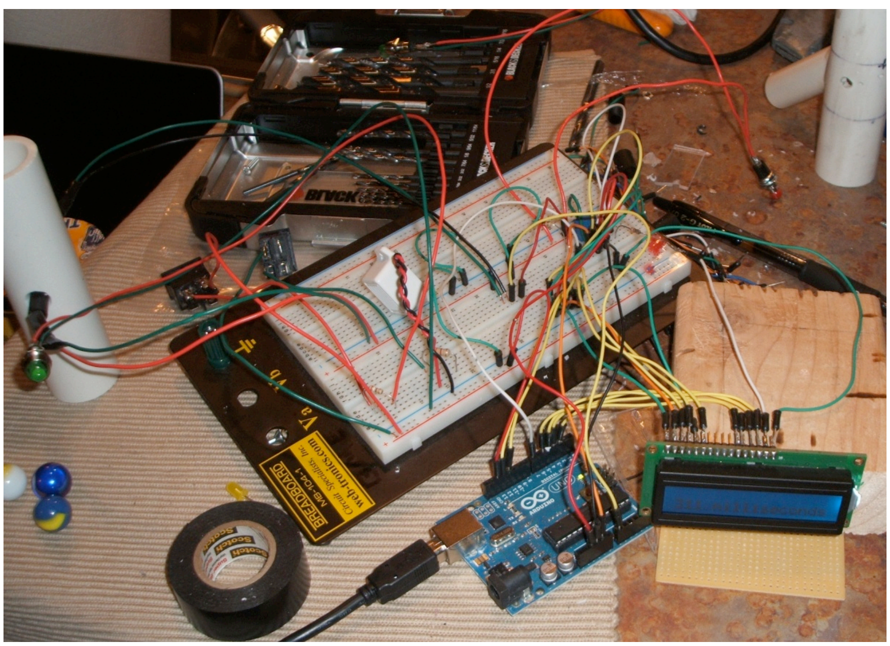

Figure 11: Circuit built on a Breadboard as soldering was underway. Note the LCD Display in the lower right hand corner, the Arduino at the bottom, the LED and buzzer, as well as the IR detector/emitter on the left.

The code was then adapted so the Arduino counted the reaction time in real time as a trial is underway. This time is displayed on the LCD screen and counts up like a stopwatch. Finally, a reaction button was incorporated to the system to allow the reaction time measurement to be stopped. The code was written so that the stimulus (whether auditory, visual, or both) would activate upon the marble passing through the IR motion sensor and stay on until the reaction button was depressed [12]. The reaction time will remain displayed on the LCD until another marble passes through the IR motion sensor to begin another trial. All electronics were wired up with 20 gauge-insulated wire and 60/40 lead/silver solder. Since the wires plugging into power, ground, analog, and digital ports of the Arduino microcontroller cannot be soldered to the board, these wires were tagged in case they become disconnected so the client (or any user) can easily plug them back into the corresponding ports as explained in [13], [14], and [15].

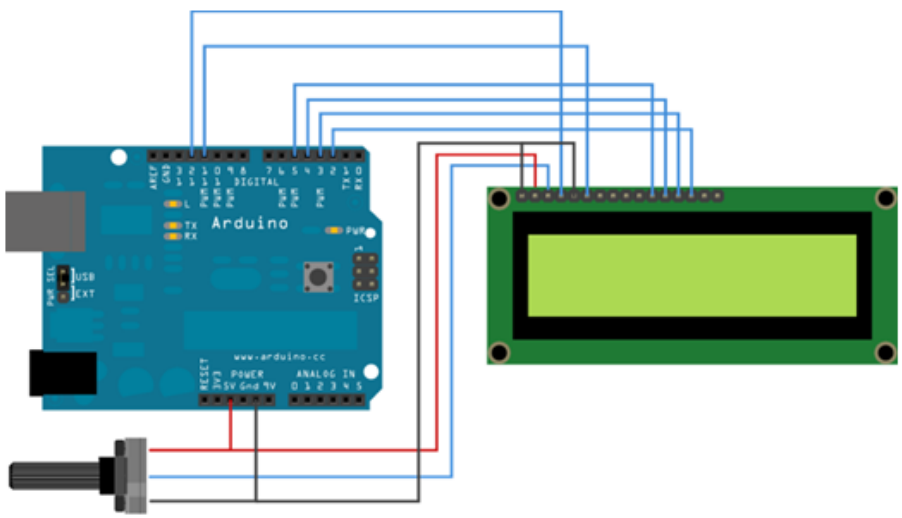

Figure 12: Connection pinout schematic for the 16x2 LCD display, Arduino, and potentiometer. This figure is taken from [15].

Budget

	Items	Cost
1.	Arduino Uno (Atmega328)	$34.16
2.	Lumber (2x4, plywood)	$24.42
3.	Acrylic and Weldon	$31.49
4.	PVC	$2.69
5.	Hardware	$47.45
6.	Electronics (Buzzer, LED's, wires, IR emitter/detector)	$35.60
7.	LED and LCD displays	$22.59
	TOTAL	**$198.46**

The team was able to remain within the $200 approximate budget given by the client. Although the budget did affect some decisions that were made throughout the design process, it didn't draw from the overall quality of the final design.

Testing

There were various tests conducted to confirm the efficiency and accuracy of the device as well as whether or not it truthfully proved that reaction time to an auditory stimulus is faster than that to a visual stimulus. The first test investigated the randomization of the time it takes for a marble to drop from the releasing mechanism. Although the releasing mechanism is designed to eliminate noise, a randomized releasing time is needed since the test subject can see the client reaching into the releasing mechanism area. However, the releasing mechanism has two half pipe ramps which allow for increased variability. The client can release the marble into the upper half pipe (which generally causes a longer randomized time) or the lower half-pipe (which leads to a shorter time). Twenty marbles were dropped into both the upper, then lower half-pipe and the elapsed time for each of these was recorded. The results can be seen in Figure 13.

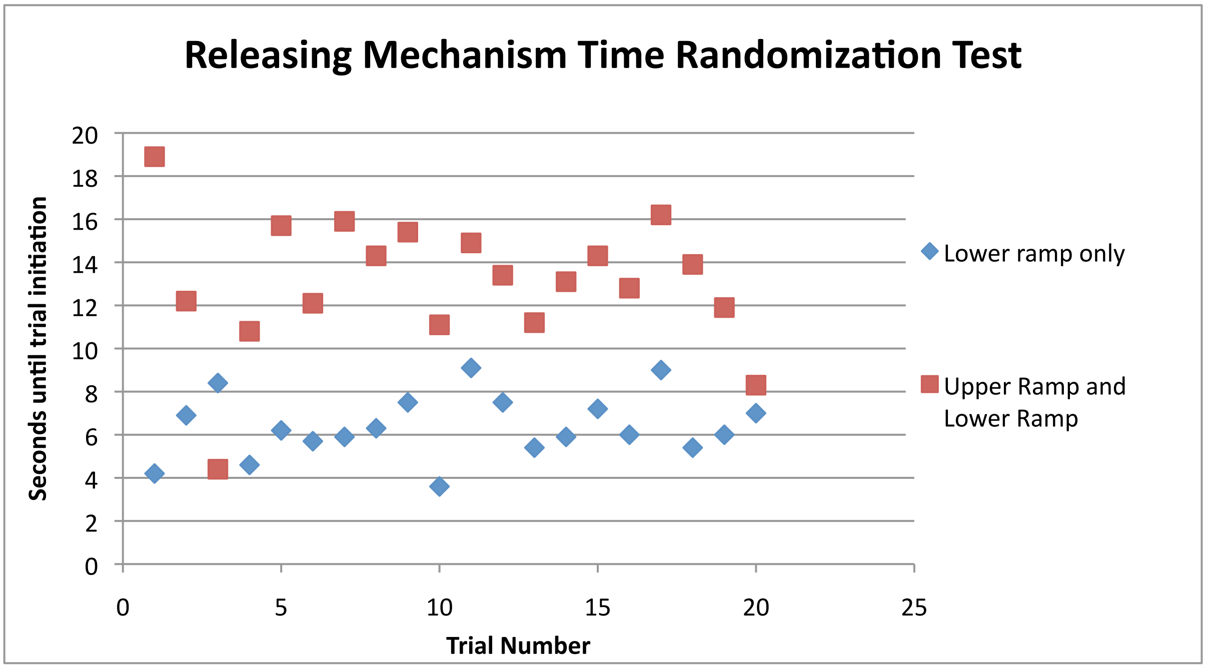

Figure 13: Results of testing the randomization time for the releasing mechanism. The Red squares correspond to the times it took for the marble to reach the trial initiation when using both half-pipes whereas the blue diamonds correspond to the times it took for the marble to reach the trial initiation when using only the lower half-pipe. Twenty trials were conducted for each method. The test yielded an average time of 13.04±3.12 seconds for both half-pipes and 6.39±1.47 seconds for the lower half-pipe. With both options considered together (since a test subject is unable to determine which half-pipe the marble is released to, the average time overall is 9.72±4.14 seconds. The trial is therefore sufficiently random to eliminate predictability.

The next test required determination of how accurately the trapdoor mechanism separates successful (i.e. fast enough trials) from failed (i.e. slow reaction trials). Figure 14 below shows the distributions of the reactions times for those trials which were sent down the successful pathway by the trapdoor mechanism. Figure 15 below shows the same distribution of reaction times for trials sent down the failed (left side) pathway by the trapdoor mechanism. Note from these two Figures that the (approximately) Gaussian distribution shows that indeed the trapdoor mechanism fairly accurately separates slow and fast trials. By analysis of the two tests against each other, it appears that reaction

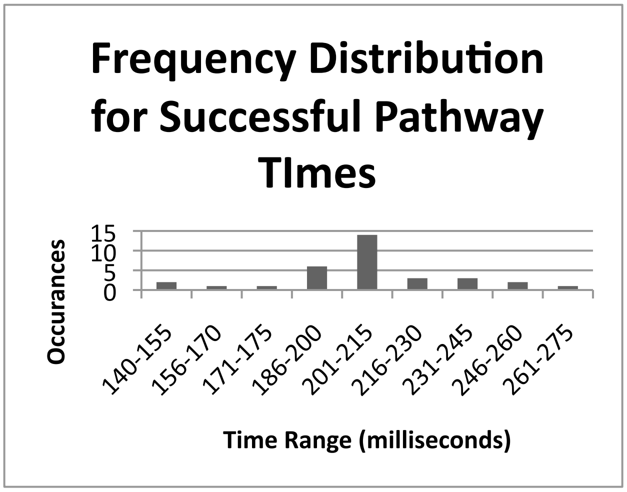

Figure 14: The distribution of time ranges for the trials which were deemed failures by the trapdoor mechanism. The marbles in these trials were sent down the left portion of the device.

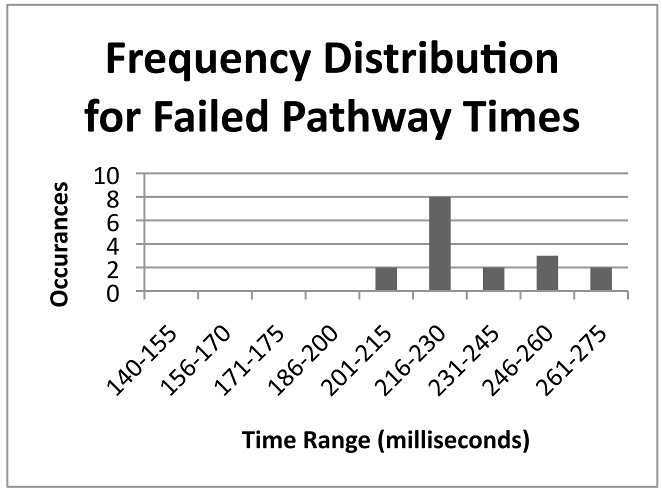

Figure 15: The Distribution of time ranges for the trials which were deemed successful by the trapdoor mechanism. The marbles in these trials were sent down the right portion of the device.

times above 215 milliseconds are mostly sent down the failed pathway whereas most marbles sent down the successful pathway are under 215 milliseconds.

In many ways, the most critical test regarded verification that the auditory stimulus yielded faster reaction times than visual stimulus reaction times. This was checked with the same test subject for all tests in order to ensure for elimination of any external variables due to anatomical differences. The 19-year-old male test subject studied was asked to perform 100 reactions to the auditory stimulus and 100 reactions to the visual stimulus. The trials were randomized between the stimuli presented to the subject in order to eliminate improvement of the test subject over time. The results proved quite clearly that the auditory stimulus allowed faster reaction times than the visual stimulus. The 100 auditory stimulus trials yielded an average of 159.65 ± 29.52 milliseconds. The 100 visual stimulus trials, on the other hand, gave an average reaction time of 186.8 ± 25.52 milliseconds. The average reaction time for the visual stimulus was entirely beyond the standard deviation range of the auditory reaction times. This essentially means that the final device undoubtedly fits the constraints of the project. Additionally, the overall weight of the final product was 16.9 kg. The device can be set up/torn down in approximately 8 minutes with two people. Set-up requires that all components are correctly aligned however.

Finally, a full test was conducted at Madison East high school with 20 high school students. Their reaction times ranged from 159 milliseconds to 386 milliseconds. The main purpose of the test was to get qualitative data about the device and see whether the kids liked it or not. The reactions we got were all positive. The kids all thought that the device was "really cool" and enjoyed testing their reaction times. Some kids got competitive and kept trying until they got a "winning" reaction time, which is also an objective of the design. It is noted that an additional piece must be added to the top funnel on the losing side so that marbles can't fly out of it. This test helped determine slight improvements that need to be made so that the device is fully functional. In addition, the test verified that the device is appealing to the target audience.

Improvements

Although the team developed a fully functional device which operates within the guidelines for the design, there are some improvements that could be made before a second generation prototype was made. Some changes would greatly improve the device while others would only make visual enhancements.

One of the most critical improvements on the device involves the frame. With an even sturdier frame and Rube Goldberg components, the overall device wouldn't be nearly as fragile during transportation. Even though the current prototype is collapsible, some components are fastened in such a way that any sort of significant shaking or shifting of the device during transportation poses the potential to break those components. Although the device is well within the weight requirement, there is potential to have a better device by eliminating some of the weight, thereby also improving the ease of transportation.

The reaction time device in its entirety should last 10 years. The solvated acrylic bonds last a long time when done well. However, the bonds are not strong enough to withstand large amounts of pressure or impact. For example, if someone fell against the display while it was in use, the acrylic pieces probably wouldn't hold and would have to be fixed. In addition, although the wiring is protected well, the soldered wires are fragile. Overall, durability of the components could be improved.

Another improvement deals with the releasing mechanism. As discussed above in testing, the releasing mechanism sufficiently randomizes the time between releasing the marble and actually starting a trial. However, developing a way to eliminate noise from the releasing mechanism would prove beneficial in a later prototype since it would remove any potential of a test subject being able to predict or anticipate a falling marble.

Furthermore, the trapdoor mechanism could be improved. Currently, the trapdoor effectively sends marbles down either the failure or successful pathway according to the reaction time of that trial. However, this mechanism isn't always 100% accurate. As seen in the testing, reaction times in the intermediate ranges could be sent down either pathway on any given trial. Developing a trapdoor which would clearly send marbles down a specific pathway pending a specific time would improve upon this.

The threshold settings of the Arduino code regarding the infrared detector are affected by light. If the lighting of the environment changes intensity, the threshold setting in the Arduino code may have to be changed. Therefore the operator of the device would have to understand the programming and be aware of how to modify the code. This makes the device harder to operate and presents another complication for the users. It could be improved by adding code that accounts for varying light intensities in the environment.

Aesthetics could be improved extensively by painting the plywood, improving rough edges and misshapen acrylic pieces, and adding more words onto the display in empty spaces describing random facts about auditory and visual reaction time and how they compare. Also, the title of the display could be painted better and the color scheme could be improved. With time, these improvements could easily be implemented.

Ethical Considerations

Throughout the design process, any potential ethical considerations of the design must be thought out. Currently, there are no demonstrative devices for reaction time measurement on the market, yet the team must be careful to avoid any sort of copyright infringement or patent copying. More specifically, as demonstrated by Dr. Yin, pervious devices have been built to demonstrate this reaction time phenomenon, but not at a large scale. Any and all ideas incorporated into the design should be entirely original. Any sort of information used throughout the process of product development must be referenced in all documentation. The altercations made to any materials and components purchased during the fabrication process didn't conflict with laws and guidelines placed upon those components. User safety is a fundamental concern in any project, especially when the user audience involves children. The team designed and fabricated all components to ensure user safety throughout the duration of the device's lifetime. Mechanical components were constructed such that safety concerns could be eliminated. For example, the collapsible structure weakens the frame, so a diagonal support was added in the final device. As for electrical fabrication, all electronics pieces were kept out of the test subject region of the device to ensure electrical safety to both the users and to possible electrical fires. As is the case in any sort of electric device however, shorts are still always possible under some situations.

Further ethical considerations involve the testing of the device. The device was truthfully tested and statistically analyzed without bias. The data, though from the college age group, truthfully tested the reaction times in the exact same way a child in the target audience would be asked to run the device.

References

[1] Kosinki, Robert J. (2010). Clemson University. A Literature Review on Reaction Time.

[2] Woodworth, R. S. and H. Schlosberg. 1954. *Experimental Psychology*. Henry Holt, New York.

[3] Kemp, B. J. 1973. Reaction time of young and elderly subjects in relation to perceptual deprivation and signal-on versus signal-off condition. *Developmental Psychology* 8: 268-272.

[4] Marshall, W. H., S. A. Talbot, and H. W. Ades. 1943. Cortical response of the anaesthesized cat to gross photic and electrical afferent stimulation. *Journal of Nerophysiology* 6: 1-15.

[5] Brebner, J. T. and A. T. Welford. 1980. Introduction: an historical background sketch. In A. T. Welford (Ed.), *Reaction Times.* Academic Press, New York, pp. 1-23.

[6] Reimers, S. , & Stewart, N. (2007). Adobe flash as a medium for online experimentation: A test of reaction time measurement capabilities. *Behavior Research Methods*, *39*(3), 365.

[7] Eckner, J. T., J. S. Kutcher and J. K. Richardson. 2010. Pilot evaluation of a novel clinical test of reaction time in National Collegiate Athletic Association Division I football players. *Journal of Athletic Training* 45(4): 327-333.

[8] Yin, Tom. (September 10, 2010). *Personal Communication/Interview.*

[9] Farmer, D. (1995). Children take learning into their own hands. *Childhood Education*, *71*(3), 168-169.

[10] DeuS. (2010). IR Emitter and Detector. Retrieved November 29, 2010 from: http://www.arduino.cc/cgi-bin/yabb2/YaBB.pl?num=1282017225

[11] Badger, Paul. (2008) Arduino Playground. Stopwatch. Retrieved December 4, 2010 from: http://www.arduino.cc/playground/Code/Stopwatch

[12] DojoDave (2005). Arduino Playground. Button. Retrieved December 4, 2010 from: http://arduino.cc/en/Tutorial/Button

[13] Hitachi (1999). HD44780U (LCD-II) Dot Matrix Liquid Crystal Display Controller/Driver. Retrieved December 4, 2010 from: http://www.sparkfun.com/datasheets/LCD/HD44780.pdf.

[14] Sparkfun Electronics, LLC. Basic 16x2 Character LCD Display. Retrieved December 4, 2010 from: http://www.sparkfun.com/products/791.

[15] Arduino IDE. Arduino.cc. Schematic pinout diagram for the 16x2 LCD display to Arduino. Received December 6, 2010 from: http://www.arduino.cc/en/Tutorial/LiquidCrystal

Appendix

Arduino Programming Code

```
long startTime ; // start time for stop watch
long elapsedTime ; // elapsed time for stop watch
int fractional; // variable used to store fractional part of time

int sensorPin = 0; // named sensor pin
int sensorValue = 0; // set iniial sensorValue
int threshold = 65; // set threshold for reaction to start

#include <LiquidCrystal.h> // include the library code:

// initialize the library with the numbers of the interface pins
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);

void setup() {

lcd.begin(16, 2); // set up the LCD's number of columns and rows:

Serial.begin(9600); // sample the input from the detector at baud rate 960

pinMode(7, INPUT); // set pin 7 to input
pinMode(8, OUTPUT); // set pin 8 to output
pinMode(13, OUTPUT); // set pin 13 to output
digitalWrite(9,HIGH); // set pin 9 to high and turned on ir emittor

}

void loop()
{

sensorValue = analogRead(sensorPin); //sets sensorvalue equal to ir detector value

Serial.print("sensor = " ); // prints the sensor value to the serial screen
Serial.print(sensorValue);
```

```
if (sensorValue <= threshold)

{
startTime = millis(); // store the start time

digitalWrite(13, HIGH); // turns pin 13 on

while (digitalRead(7) == LOW)
{

lcd.setCursor(0, 1); // set the cursor to column 0, line 1

lcd.print(millis()-startTime); // print fractional part of time

lcd.print(" milliseconds"); // label for time elapsed

}

}

else

{

digitalWrite(13,LOW); // set leds and buzzer off

}

}
```

Product Design Specifications

Problem Statement: A device is desired that will measure and compare simple visual and auditory reaction times in order to demonstrate the difference between audio and visual processing times in a classroom setting. The device must be intriguing and intuitive for its target audience. There is also the potential to incorporate other sensory reaction times into the device.

Client requirements

- Portable to allow for easy transportation and setup
- Simple and easily operable
- Low cost (a maximum of $200)
- Digital time display
- The device must be thought-provoking and appealing
- Must be accurate (down to the millisecond)
- Allow for bimodal testing
- Must clearly demonstrate that auditory reaction times are faster

Design requirements

1. Physical and Operational Characteristics

a. *Performance requirements*: This device must be able to operate on a continuous basis for short periods of time during demonstrations. It must be able to be disassembled and loaded into the back of a van for transportation. Performance must clearly demonstrate quicker reaction times for auditory vs.

visual stimuli.

b. *Safety*: Must be child-safe. All electrical components must be secured in a safe manner. Moving components should not pose any harm for user. The device should always be operated by an adult and small children must be supervised while using the device. The components of the device must be easily sterilized.

c. *Accuracy and Reliability*: The time measurements must be accurate to the millisecond. Device must be designed for repeated assembly, disassembly and operation.

d. *Life in Service*: Must be designed for use at a maximum of 10 times a year for a duration of 4 hours at a time. Device should be designed to last indefinitely with minimal maintenance.

e. *Shelf Life*: Device should be designed to last indefinitely with minimal maintenance. Any batteries used should be easily replaceable.

f. *Operating Environment*: Operation will be in a classroom environment at room temperature. Device should be stored in standard indoor environment. The device must be protected against various weather conditions while in transit.

g. *Ergonomics*: The device should be operable with adult supervision for ages 6 and up.

h. *Size*: Must be able to be disassembled and transported in the back of a van.

i. *Weight:* Easily transportable by a single adult (<40 lbs)

j. *Materials*: All materials are allowed baring anything that poses a threat to user (i.e. common allergenic materials).

k. *Aesthetics*, *Appearance, and Finish*: Appearance should be the strong point of the device. It must be attractive to all audiences with an emphasis on middle school-aged children.

2. Production Characteristics

a. *Quantity*: One is desired

b. *Target Product Cost*: Minimal cost is preferable with a limit of $200.

3. Miscellaneous

a. *Patient-related concerns*: In order to limit the spread of common germs and illness the device must be easily disinfected.

b. *Competition*: The intention of building this device is strictly for educational purposes and therefore will not compete with current devices. It will not be used for marketing purposes.