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Thesis Report

Development of interactive toy – "PLAi Board" to support early development skills of learning, motor skills and interaction skills.

TESI IN LAUREA MAGISTRALE IN

DESIGN AND ENGINEERING

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Abstract in English

Autism is widely recognized condition, and it can hinder early development of autistic children. It makes difficult for autistic children to engage in activities like interaction with other, play and learning new skills. To overcome this issues, parents of these children must give their emotional and monetary supports which sometimes take lot of effort and savings. While Play is a important activity which also initiate the development of children. It makes them learn new fundamental skills.

This project "PLAi Board" tries to support the parents through an interactive game which can be basic tool to teach and engage their children in learning basic things. This game does not replace any intervention and therapist. It only aims to support some learning activities which can be carried at home with parents' involvement in their home or comfort surrounding. The project focuses on the development of the interactive game which is easy to develop and can be accessed in every homes. It provides gamification approach to the learning activities. So, autistic children do not feel any direct pressure while a play. In conclusion, the game involves teaching the children about colors and to make them use their cognition skills and as well improve hand and eye motor skills. During the development phase, the goal of proper functioning of this gamified interactive game was procured. Testing of the prototype was executed with the children and their caretakers. During the testing, there were some points of improvement were noticed and product usage validation were done according to the review of caretakers and children response toward product.

Sommario

L'autismo è una condizione ampiamente riconosciuta, e può ostacolare il primo sviluppo dei bambini autistici. Rende difficile per i bambini autistici impegnarsi in attività come l'interazione con gli altri, il gioco e l'apprendimento di nuove abilità. Per superare questi problemi, i genitori di questi bambini devono dare i loro supporti emotivi e monetari che a volte richiedono molto sforzo e risparmio. Mentre il gioco è un'attività importante che avvia anche lo sviluppo dei bambini. Li fa imparare nuove abilità fondamentali.

Questo progetto "PLAi Board" cerca di sostenere i genitori attraverso un gioco interattivo che può essere uno strumento di base per insegnare e coinvolgere i loro figli nell'apprendimento delle cose fondamentali. Questo gioco non sostituisce alcun intervento o terapista. Mira solo a sostenere alcune attività di apprendimento che possono essere svolte a casa con il coinvolgimento dei genitori nella loro casa o nel loro ambiente confortevole. Il progetto si concentra sullo sviluppo del gioco interattivo che è facile da sviluppare e può essere accessibile in ogni casa. Fornisce un approccio di gamification alle attività di apprendimento. Così, i bambini autistici non sentono alcuna pressione diretta mentre giocano. In conclusione, il gioco prevede di insegnare ai bambini i colori e di fargli usare le loro capacità cognitive e di migliorare le capacità motorie di mani e occhi. Durante la fase di sviluppo, l'obiettivo del corretto funzionamento di questo gioco interattivo gamificato è stato procurato. Il test del prototipo è stato eseguito con i bambini e i loro custodi. Durante il test, sono stati notati alcuni punti di miglioramento e la convalida dell'uso del prodotto è stata fatta in base alla revisione dei custodi e alla risposta dei bambini verso il prodotto.

Acknowledgement

The completion of this master thesis would not have been possible without the contribution of many individuals. I would like to acknowledge and extend my heartfelt gratitude to all of them.

Foremost, I would like to thank Prof. Mario Covarrubias Rodriguez for giving me this opportunity to carry out this chance to work for special autistic children. I thank him for his timely guidance and valuable inputs in taking forward this project.

I would like to extend my gratitude towards those special children and their caretaker who came and participates in the testing and provided their feedback to me.

Index

List of figures

List of Tables

Introduction

Autism is a spectrum of conditions of neurological and developmental disorder that affects the interacting, communicating, and learning capabilities of people. It is associated with birth-related conditions but possible to be diagnosed at any age. Although, symptoms can be observed at an early age such as initial years after birth. Autism spectrum disorder is a term used to describe a constellation of early-appearing social communication deficits and repetitive sensory-motor behaviors associated with a strong genetic component as well as other causes (Lord et al. 1). In past years, autism spectrum disorder has changed in people's perception from a narrowly defined disorder to well researched known condition. People have become aware of the disorder and embraced it more as a common issue in a positive perspective. Some of the common faces of ASD in children are of having social communication deficits and repetitive and unusual sensory-motor behaviors. Every special autistic child has different behavior. One may be very verbal, bright, and enthusiastic, while another may be non-verbal and intellectually challenged. These children are visual learners who are more sensitive to their senses (Khowaja & Salim, july 21, 2015) .

However, families, teachers, and other personal support can make a huge positive difference in the life of children having autism spectrum disorder.

Interactive products have recently become popular because of their multiple feedback interactions. Whether they are children or older people, all people like to interact with this kind of smart product. There are many therapy centers where interactive products are commonly used for many activities during therapies or interventions. Especially for autistic children when these interactive devices are integrated with sensory stimulations then these devices can have a huge positive impact on children's life.

With Plai Board, the purpose is to include play into the children's therapy or in personal activity through the help of interactive technology which can help them to improve their cognition and interaction skills. Plai Board consists of the functions of musical and color learning where children can receive some sensory feedback while playing and exploring the game.

1.1 Motivation

1.1.1 Effect of autism in different age group

Theorists suggest that as we age, we gain more positive feelings about the self after we form a coherent identity during adulthood. Understanding this trajectory in the autistic population is essential. Some research suggests as autistic adults age, symptoms improve or remain stable. However, research is unclear as to why symptoms may improve. Some suggest that targeted therapies early in life may improve symptoms (Cross, 2021).

Early diagnosis and therapies are necessary for the children as they can learn the basic skills that they usually practice in early childhood, for example, Physical motor skills, Thinking skills, Communication skills, Social Skills, and Emotional skills. And, with early interventions, some children with autism make so much progress that they are no longer on the autism spectrum when they are older (Office of Communications, 2021).

1.1.2 Cost of therapies or interventions

As we know that parents and other connected people to autistic children make a vast difference in the lives of autistic children while expert physicians and therapies also help in positive development. They provide expert advice and well-researched tactics dealing with and improving the symptoms according to the child's autistic condition. However, ASD represents a substantial economic burden. Mainly due to the provision of support to adults who cannot function independently, which results in higher health care and school cost and loss of income for caregivers (Lord, Elsabbagh, Baird, & Vanderweele, 2018).

State of the art

2.1 autism spectrum disorder (ASD) therapies and interventions

In recent years, autism spectrum disorder (ASD) has been well defined. It is well known that ASD negatively affects children's ability to communicate, focus, interact, learn, and motor skills. The scope of the disorder can be from mild to severe. Currently, there is no cure found for this disorder.

However, there are many intervention services, and therapies that can be helpful for the children to learn important skills which are deficient due to ASD. How much and what kind of intervention children and adults with ASD receive vary immensely across the world and even within countries and regions. One consistent finding across many (although not all) locations is that parents with a lower educational level are less successful in obtaining

specialist interventions that could improve outcomes. In one survey about European services for less well-educated families, even low-cost and publicly funded interventions were not available to children until a year after diagnosis (Lord, Elsabbagh, Baird, & Vanderweele, 2018).

Early parent-mediated interventions

Some well-managed interventions that are less intense in nature have proved to be effective on the social behavior of autistic children. Therefore, some early behavioral interventions were developed. These interventions were the result of increasing interest in early parent-children's interactions. These interventions are parents or caretaker orientated which teaches parents how to interact with their children. These interventions teach parents or caretakers about how to connect with their children based on indirect attention. Therefore, it is also referred to as Parents mediated interventions (PMIs). These interventions are efficient because they do not need direct children's involvement. Rather these interventions are parents' children's activities where children are indirectly involved in the activities which can be brought into their homes or community settings (Lord, Elsabbagh, Baird, & Vanderweele, 2018).

These treatments that fit into the category of early parent-mediated interventions are listed here (Lord, Elsabbagh, Baird, & Vanderweele, 2018).

•Developmental Individual-Difference Relationship-Based Model (DIR) or Floor time

•Early Social Interaction (ESI)

•Early Start Denver Model (ESDM)

•Joint Attention Symbolic Play Engagement and Regulation (JASPER)

•Preschool Autism Communication Trial (PACT)

Naturalistic behavioral developmental interventions

The treatment that has received the most attention historically in North America has been an early intensive behavioral intervention. The most well-known form of this treatment is Applied Behavior Analysis (ABA), but there are many versions of this approach (Lord et al. 7).

A few years before some methods of Applied Behavior Analysis were reintroduced in different interventions such as naturalistic developmental behavioral interventions (NDBI), which includes Pivotal Response Treatment (PRT), Early Start Denver Model (ESDM), Joint Attention Symbolic Play and Engagement Regulation (JASPER), and Early Social Interaction (ESI). These treatments comprise the essential elements of play, social interaction, and communicative initialization for the child to practice in a playful manner. Also, teachers, caretakers, therapists, or teachers have a responsibility to execute these before mentioned approaches to practice skills like languages or cognitive tasks (for example, matching or sorting).

Additionally, another well-known treatment that is extracted from ABA techniques is TEACCH (Treatment and Educational of Autistic and Communication Handicapped Children and Adults). TEACCH is a technique to use a physical or structured environment, sometimes a classroom to make children more independent and communicative.

Overall, therapies mediated by parents have been seen to be effective for communicative interaction and other ASD symptoms over the period. This mediation involves usually one-to-one interactions that provide good progress to language development and cognition.

Early naturalistic developmental behavioral interventions (Lord et al. 7)

•Early Achievements

•Enhanced Milieu Teaching (EMT)

•Early Start Denver Model (ESDM)

•Incidental Teaching (IT)

•Joint Attention Symbolic Play Engagement and Regulation (JASPER)

•Pivotal Response Treatment (PRT)

•Project ImPACT (Improving Parents As Communication Teachers)

•Reciprocal Imitation Training (RIT)

•Social Communications/Emotional Regulation/Transactional Support (SCERTS)

2.2 Use of interactive or sensory products for ASD affected children

Parents with autistic children try to help their children for them to live their life happy and normalized living. However, with autism, living is a little different. It is difficult to achieve education for some children and to learn new skills. Education and being able to learn new skills are very essential. Autism is non-curable but there are some special techniques of treatments that can reduce its effect in children's life. And, in this case, interactive products can be helpful for both children and parents.

Interactive systems for children with ASD are defined as systems that respond in real-time and in a personalized manner by understanding the behaviors of each child. This is a software-based solution that engages the interest of children in a comprehensively designed system focusing on specific behaviors. At present, the applications of interactive systems have been proven to change the lives of children with ASD. The outcomes evidently show that the employment of these systems helps the affected children to interact, socialize, communicate, and learn in novel ways. Various reviews have been carried out on teaching different skills to children with ASD by using interactive systems. Some studies demonstrated improvement in the learning of these children after they had used the interactive systems (Khowaja & Salim, july 21, 2015).

Interactive toys including sensors are a very common approach to provide effective results. Interactive toys including sensory interaction help autistic children in relaxing, focusing, and other activities during some tasks. Autistic children are either Hyper-Sensitive or Hypo - Sensitive Children. Hypersensitive children are over-sensitive or over-responsive to the stimulants while Hypo Sensitive children are under-responsive to the senses. Sensory interactive toys help them to diverse their senses for the stimulants in a positive way. In this way, they feel less stressed while performing some tasks. As a result, they give their natural play and performance to the activity.

The use of interactive toys to help children with autism is becoming more and more common. There are many different types of interactive toys available, appealing to one or more of the different senses. Interactive toys work to engage a child’s senses in an enjoyable way. Interactive toys used for autism can help children focus better, calm

down, and relax, however, sensory toys do not replace formal and evidence-based treatment for autism spectrum disorders. In the end, Interactive toys are meant to help a child learn more about their senses in a fun way. Using play, a child with autism may better understand their senses and how to manage them (The 10 Best Sensory Toys & Gifts for Children with Autism).

2.3 Examples of interactive products

Synchrony

Synchrony is a therapeutic instrument that aims to create child and parent interaction with the help of music. It allows each other to share their emotions through music play.

A social-emotional barrier exists between parents and children with autism, often leading to dejection and decreased self-efficacy for both parent and child. Improvised play in music therapy, a process that simulates mother/infant social play, helps to bridge that gap. However, the technical nature of improvised music play can intimidate parents from practicing it alone with their children (Synchrony — Kenneth Tay).

Figure 1 : Synchrony Interactive toy

Mosaic

A tool designed for the school inclusion of children with autism spectrum disorder, through the training of teachers and the use of customizable and programmable interactive objects. MOSAIC proposes itself not only as a tool for the inclusion of children with autism in the classroom, but also as a means of training and development of broader skills both for teachers, through the training course, and for children, who can learn to be welcoming towards their autistic companions and appreciate their skills by carrying out fun and instructive activities together (Foundation, 2020).

Figure 2: Mosaic Interactive toy

Teo

Teo is a non-humanoid robot that is used in ASD treatments. Teo has an egg-like shape with two "fake" arms, is yellow and its dimension is purposely designed to be able to be hugged by children. It is further possible to adapt Teo´s appearance to one´s liking through the configuration of its eyes, mouth, and eyelids. The robot can be remotely controlled and has the capability of autonomous reactions. Teo: invites to interact, it is happy when stroked and scared when hit (Milani, 2020) .

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Figure 3 : Teo Non humanoid Robot

Pooki

Pooki is a toy designed for all children but is particularly attractive to Autistic children. Pooki is designed to help parents, especially parents of Autistic children find a toy that suits their child, rather than hoping their child suits the toy. Using research data, every aspect of Pooki is designed with a purpose and function.

When it comes to what toys are currently available for Autistic children, it is observed that many toys often generalize all Autistic children into one broad category. Every child with Autism has unique genetics, causes, and triggers, not one child is the same as the next. This created a need for a toy that truly reflects the research that has been undertaken into what makes a toy attractive and beneficial to Autistic children; At the same time, removing the stigma that is often associated with 'special toys for special children by creating a toy that all children can play with (Dinh, 2015) .

Figure 4 : Pooki toy for autistic children

Goal Definition

3.1 Target Group

Autism is a lifelong condition that can be developed from birth. Therefore, a person can have symptoms of autism spectrum disorder all in his/her life. Children are very dependent on their parents or caretaker. From birth to adolescence, it is very important age for every child to learn something. And this stage defines the development of the person whether it is how they learn about self-confidence or how they operate in their surroundings. However, teenagers and older age people learn how to cope with the symptoms of autism spectrum disorder.

Thus, Children of development age ranging from 4 to 7 years are considered as a target.

In some research, it has been found that some early care for autistic children and teaching them about the daily task which they find difficult to do because of autistic symptoms can show very good development in their life. Furthermore, they develop their own ways to deal with autism. In some cases, symptoms of the autism spectrum disorder were not observed.

In recent years, children are always surrounded by technology whether it is a mobile screen or technological toy. Interactive games are very commonly used by children or their parents to engage and to learn. However, most of the interactive games are screen embedded devices such as mobile or tablets. Usually, it can be seen that parents use their mobile or tablets to engage their children whether it is for keeping them busy or making them learn something. Although using mobile screens is not good or well for children's sight or mental health. They are less engaged with any physical games rather than using daily virtual learning or activities. Here, physical interaction can play a vital role where autistic children can learn from these games by having different sensory feedback while engaging with the games physically.

In this project, I have tried to provide an interactive experience to the children through which they can learn while having some play activities. This product consists of different tasks of musical play and color coding with audio signals. With its interactive nature, they can practice focusing on the tasks. This interactive product imitates some of the activities

which some therapist uses in their early parent-child mediated therapies to bring these therapies to children's comfort zone whether it is their homes or their therapy centers.

Findings and observation

4.1 Desk Research

Some aspect of the project is to bring some early parents mediated interventions to the more reachable surrounding for the children and parents. I performed some desk research and as well some interviews to understand the parent's overview of having autistic children and the emotional and financial support these parents provide to their children.

One of the commonly found behaviors is attention atypicality. Attention atypicality is often found in individuals with autism spectrum disorder (ASD), with reports of initial difficulties in attention related to the development of core ASD symptoms. Attention difficulties such as disengagement are present from the first year of life in children with ASD and may extend to the Broader Autistic Phenotype. Difficulties are also exhibited in sustained attention, selective attention, and executive functions such as inhibition, planning, set-shifting, and cognitive flexibility. Importantly, attention capacity is closely linked to learning and academic performance, including in the context of ASD children and adults, who tend to show difficulties in writing and reading comprehension, and math. Thus, children with ASD may face a double barrier to academic success in schools both from their core ASD symptomatology and their attention atypicality (Paula, 2021).

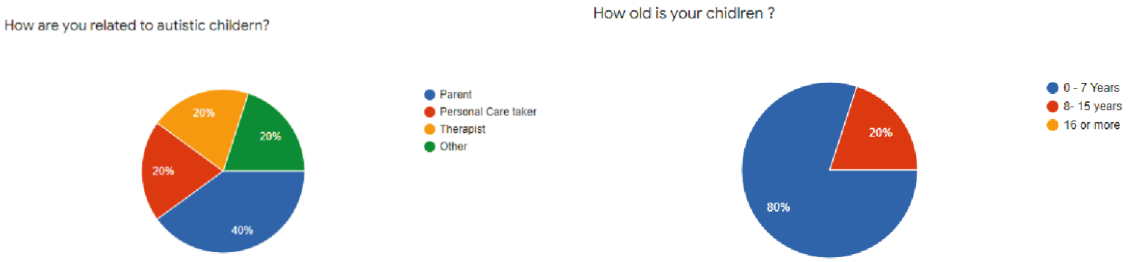
4.2 Interview of parents of autistic children

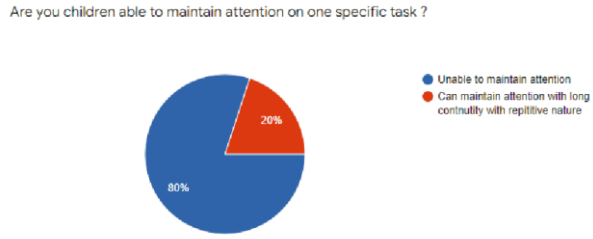
During the research phase, I conducted some survey from parents, caretaker, or therapists to understand the user need. Key points were taken in consideration while designing the device. Additionally, some interviews were done with parents personally to understand their perspective for better analyzing the issue.

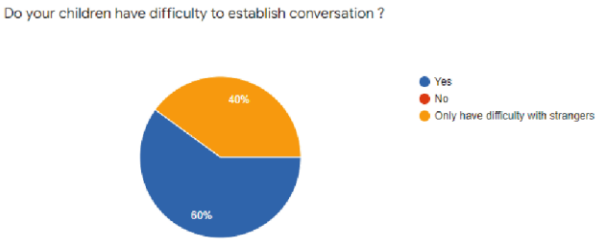
There are some questions which were chosen to have a basic understanding for the project about parents and their autistic children:

- How are you related to autistic children?
- How old are your children?
- Are your children able to maintain attention on one specific task?
- Do your children have difficulty establishing conversation?

- Does your child have any super sensory stimulation?
- Do color and music attract your children's attention?
- Do your children play any interactive games?
- Do you think that early intervention therapies for autistic children are expensive and take your saving?
- Do teaching your children basic development skills difficult and take more emotional fatigue?
- Would you prefer an interactive toy to teach your children about music, color, and shapes that can give basic development skills to your children?







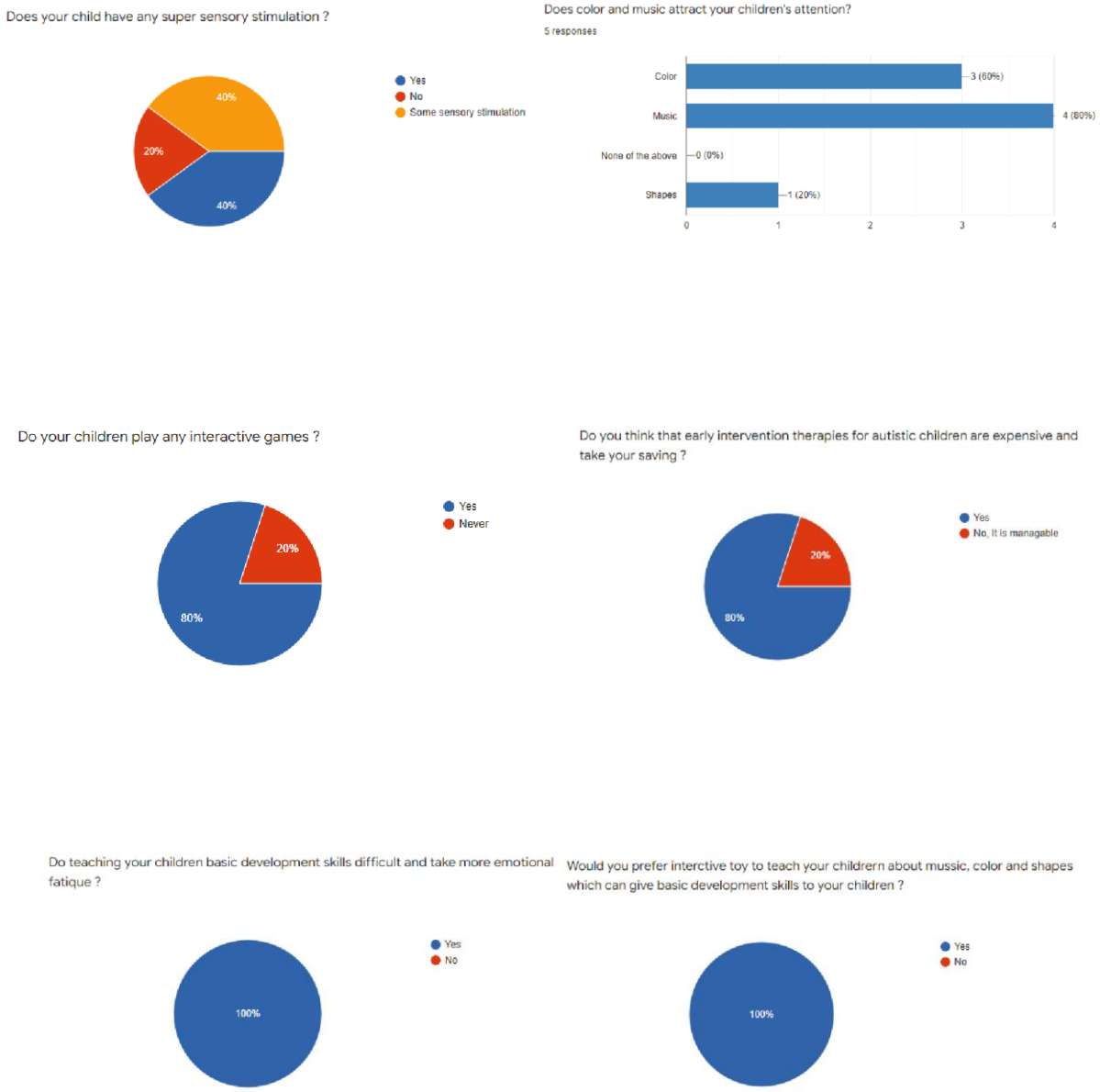


Figure 5 : Research survey

I also looked for some already done interviews of parents who have autistic children and try to understand the financial and emotional expenses of all the needs that autistic children require.

1. <u>Anne</u>

Anne is the mother of a kindergarten child, Brandon, diagnosed with autism. Brandon's diagnosis changed periodically between Pervasive Developmental Disorder-Not Otherwise

Specified and autism beginning at the age of two and one-half years. The diagnosis he was given was dependent on the specialist conducting the assessment. Anne was forced to quit her job due to the inability to find daycare for Brandon and became a stay-home mom. Anne spent much of her time educating herself about ASD and has become a leader for a support group for parents. (Lori A. Kalash, 2012)

2. Beth

Beth is the mother of a preschool child, Cory, diagnosed with autism. She had many delays in her search for answers regarding Cory's behavior and was told to "wait and see" and that he was fine. Beth was given very little guidance from the medical community and became a self-leaner. She spent 10 years earning her four-year degree and then was forced to quit her job due to the lack of appropriate daycare for Cory. Beth has become a leader for a support group for parent. (Lori A. Kalash, 2012)

The key aspect of learning is paying attention. And when we pay attention, we focus on something and ignore other things. It involves being aware of what needs to pay attention to. For children, it is a key learning from a small age. However, for some autistic children, it is difficult to learn how to pay attention (raisingchildren, 2021). It gets more difficult when for them it is hard to sit still for long or when getting distracted very easily. Different autistic children can have different attention abilities. Some children cannot pay attention to one thing, and it is difficult to do tasks that do not interest them. They can prefer to consume themselves in a task that requires shared focus our attention. On the other hand, some autistic children can focus very long time without any interruption. They are very well able to shut other senses while they are focusing on one thing. For them, it is also difficult to adjust to the change of the activity on which they were focusing or consumed fully.

Figure 6 : Toys found in market research

While deciding a theme for the interactive games There was research done in the market by going to the toy stores and supermarkets to understand toys available for children. It was interesting to understand how they include the learning aspect in the fun activity. There were some award-winning toys that develop children's concentration and imagination with stacking blocks.

Figure 7 : Toys found in market research

After researching the toys, I found that most of the toys were focused on block-building activities. They were available in different colors to include some combination of activities including colors and shapes. This kind of shape supports some basic skills development.

Supporting Cognitive Development

Building with blocks supports children's cognitive development. As children build, they are subconsciously creating goals for what they'd like to accomplish during play, whether it's building something specific, developing a pattern, or exploration of how the blocks fit together.

Supporting Gross and Fine Motor Skills

Through their own exploration of blocks, children develop fine and gross motor skills. As they manipulate the blocks during play, their hand/eye coordination strengthens.

Additionally looking for the static toys, I was finding the new interactive technologies which I can integrate with the above-researched games to obtain the optimum

outcomes for children learning. There are some well-suited fully interactive technologies that are being used for autistic children. These technologies include depth sensors able to detect body motion, sensor embedded lightning, Walls integrated with touch sensors, etc.

Figure 8 : Cariad Interactive - Somatic Concept

The Somantics concept is a suite of applications that use touch, gesture, and camera input to encourage, capture and amplify the interests of young people with Autistic Spectrum Conditions and other related communication difficulties. The overarching goal of Somantics is to promote greater self-awareness, confidence, and independence (Coriad Ineractive, 2017).

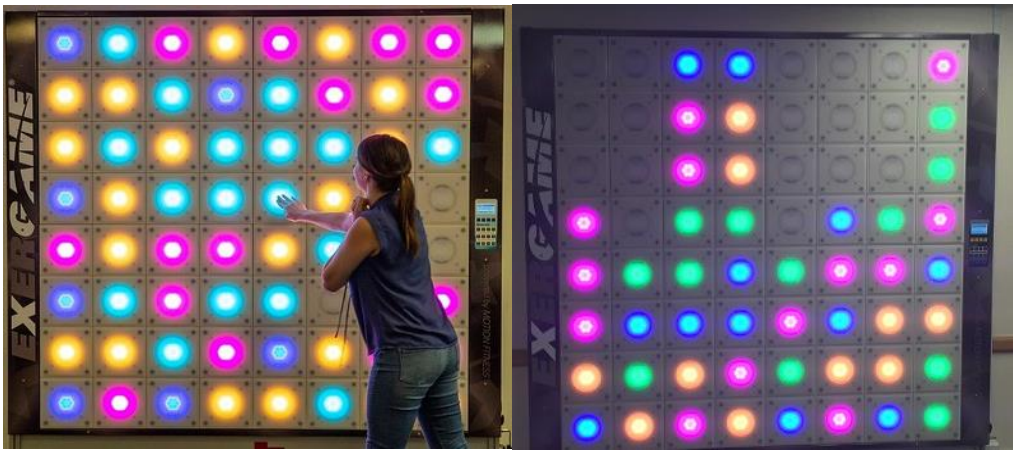


Figure 9 : T-wall interactive Wall

The tWALL 64 is an interactive touch wall that helps improve participants' reaction speed, coordination, motor skills, endurance, and decision-making processes. This interactive

high-tech wall uses light-up targets that are deactivated by touching them. With over 40+ included game programs, and the ability to create your own custom games, the wall can be used in a variety of ways from sports performance to rehab and physical therapy, at the health club, or as an exciting game. Whether training for power, agility, endurance, flexibility, or reaction, tWALL tests your personal limits resulting in the ultimate fitness gaming platform for any challenge (ExerGame, n.d.) .

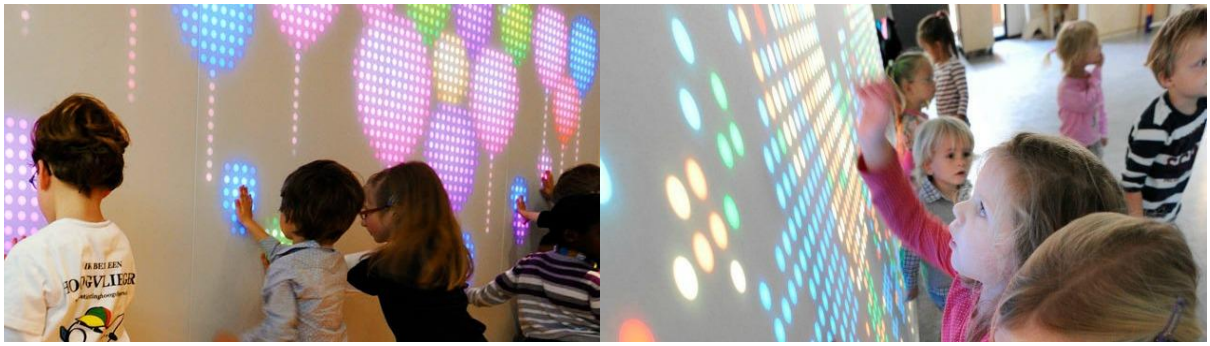


Figure 10 : Nebula interactive wall

The Nebula is an interactive wall that uses thousands of LED lights and advanced interactive technologies to keep children and adults engaged in unique interactive experiences for hours at a time. The lights contain sensors, and the wall is designed to respond to touch by emitting light, allowing users to play with the effects that they create. It is designed to engage the players' imagination and motivate them to keep moving in a relaxed interactive environment. It offers a versatile range of interactive games and limitless possibilities, which make the wall suitable for many different environments and settings (FG Team, 2015).

Plai Board is designed by taking some aspects of these examples. These technologies and their approach to assisting children in playful activities were taken as a part of inspiration to develop Plai Board.

Product Design

Plai Board is a smart interactive play-board that tries to imitate some basic tasks for helping autistic children in their early development skills and provides a way to establish a connection between children and their caretakers or parents. Plai Board consists of musical color play for children with musical and color LED feedback. The toy can be guided by parents or caretakers.

5.1 Analyzing Requirements

Information about children and their parents was gathered to understand this domain. The process involved some interviews with the parents or caretakers of autistic children about their experience of having autistic children in their life. As a result of the deep research, there was enough information to understand that early mediated intervention available to autistic children are still needed to be broadly available. Some restrictive parameters which restrict the widespread of interventions were the deep investment of parents towards their autistic children. Parents had to invest their life savings for the therapies or interventions. Instead of being parents of a normal child, parents with an autistic child must pay more attention to teaching their children basic skills. They need to find supervised methods or techniques which will work for their children. To find well-suited activities, they need to approach the therapists and some specialists which further cost their savings or monetary conditions. As discussed, that some autistic children lack different skills such as some really lack motorized skills, some lack attention, some have repetitive nature in their behavior that it is difficult for them to change the activity and attention over it. Therefore, children with autism need special care for them to learn these basic skills which are very important for living and learning. And Parents with autistic children seeks to take support from some care-taking centers, specialized caretaker, or child therapist to support their children for the development of these skills and to teach them how to cope with these conditions.

Plai Board does not aim to replace child therapy's role, caretaker role, or supporting interventions. Plai Board intends to provide some playful activity that teaches children and is able to help autistic children to learn basic motorizing skills, cognitive thinking, desired attention capabilities, and creative thinking. In addition, it includes children and parents interaction which helps to build important connections between parents and their children. Thus, Plai board is a tool that is brought to the children's desirable surroundings such as in their home and it can also be used in intervention centers. It can be an easy and cheap interactive toy that can be brought by parents and caregivers to have a learning tool for their children when they prefer to assist their autistic children.

5.2 Ideation

5.2.1 Choosing interesting focusing activities for children

Autistic children are much more inclined toward sensory feeling, and it is interesting to use this special ability of children to choose interactive activities through interactive toys. So, they can playfully with interest and with interacting with their parents or others. Some of these interactive toys create an opportunity for both children and their parents to fill the communication gap between them.

Some factors were taken about to choose the activities which children can play and can learn some early development skills.

In comfortable surroundings: Autistic children are not well used to change in their surroundings, and it is difficult for them to readjust to the new surroundings, near to new people. Therefore, they prefer to stay in known surroundings and with known people, such as a home. Many children who are new to their therapist or therapy center are more likely to feel uncomfortable for a few initial days until they don't feel safe and comfortable.

Maintaining required attention: Some children face difficulties in focusing and paying attention to specific tasks. Adding gamification to the task of learning, it can motivate the child to engage in the task. Interactive toys make this process more fun and allow children to pay indirect attention without having a feeling forced into the activity.

Visual learning: Children are great visual learners. Most interactive toys use this feature to make children engage in the task. Some examples include mobile games, Screen-based robots which show visual interaction and feedback to the children whether though the screen or through LED diodes. This gains their curiosity to understand the process and to learn the meaning of the feedback.

Improve cognition skills: Smart toys having gamification activities that have problem-solving activities make children improve their cognition skills. These toys make them learn new activities by integrating traditional games with smart and playful interaction like color sorting, building blocks with color-changing buildable cubes. These kinds of toys make children think while they play.

Improving Communication skills: Interactive toys can be an interesting way to teach children about interaction and communication. Devices with audio or visual feedback depict sometimes as a companion toy when designed with the goal of having a character. Autistic children suffer from loneliness and this kind of toy improves their communication skills in their own comfortable surroundings. While having a toy that needs both children

and parent interaction can be much more helpful in order to establish the connection between children and parents.

Sensory processing: Some smart toys provide different sensory experiences to attract the children's attention. Additionally, autistic children have two levels of sensory processing: Under sensory procession and Over sensory processing. So, introducing these senses playfully to the children which either make them comfortable or uncomfortable can teach them to tackle it or learn how to cope with it.

While designing the product, I focused on the shape of the product which should be easily relatable to the children. On the other hand, Products for children should have a domain of play. The solution to add playfulness to the product is achieved through interactive play. Having a smart toy lets children connect with different senses. In order to do that, there were many children's games analyzed to understand the domain of toy functionality. There were many autistic games that had different senses of children in order to play. There were some interesting benefits of involving the sensory play in this toy while they learn or develop their cognitive skills.

As explained previously, the Plai board is also based on musical coding which gives children an audio sense while doing some tasks with this. This audio sense is integrated with visual color LED feedback.

5.2.2 Shape design: To design the aesthetics of my project, I researched the market available toys and try to understand how they attract children's attention. Some toys are very well designed that they can easily be connected by the children.

And design for children has long been overlooked. “Toys are not really as innocent as they look,” affirmed the pioneering mid-century designer, Charles Eames; “Toys and games are the preludes to serious ideas.” The objects with which we surround children become central to their experience and perception of the world. Frank Lloyd Wright claimed that the woodblocks that he played with in kindergarten sparked the start of his development as an architect (Birks, 2022).

While exploring different shapes, I focused on the design which relates to children in terms of what they are surrounded by, what they see on television, what they admire and listen to. On the other hand, based on my research some of the aspects of the game were defined which was that the game will be having stackable objects which will have assigned colors. Each color will have particularly specified musical notes to give

musical output. Therefore, there were some preset shapes that could have been as base form.

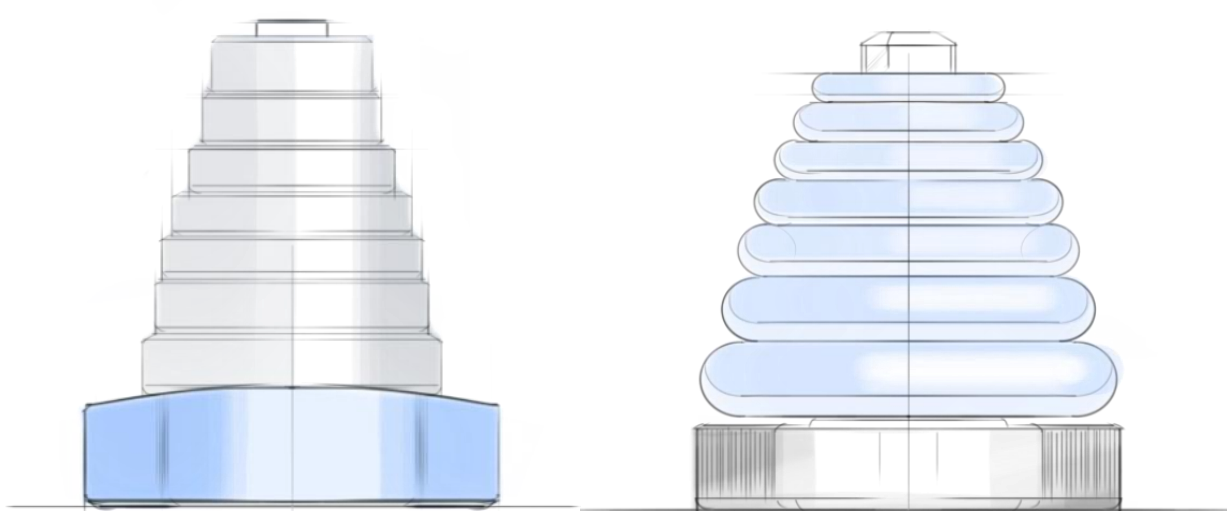


Figure 11 : Ideation Sketch

I proceeded with basic stacking shapes which I could have been found in market available toys. I analyzed the shapes and why they are mostly designed with basic shapes and forms which children can easily recognize and reimagine.

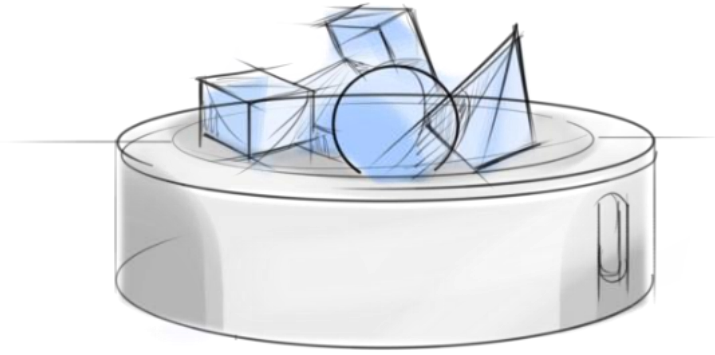


Figure 12 : Ideation Sketch

There were some games with shapes that were focused on engaging the children with the understanding of shapes and their color-coding rather than stacking the object. Here the stacking was less emphasized but as they add the shapes in the bowl-a-like container. It was able to give them feedback about their activity. The activity is quite interesting but it is less focused on motor skills of eye and hand coordination.

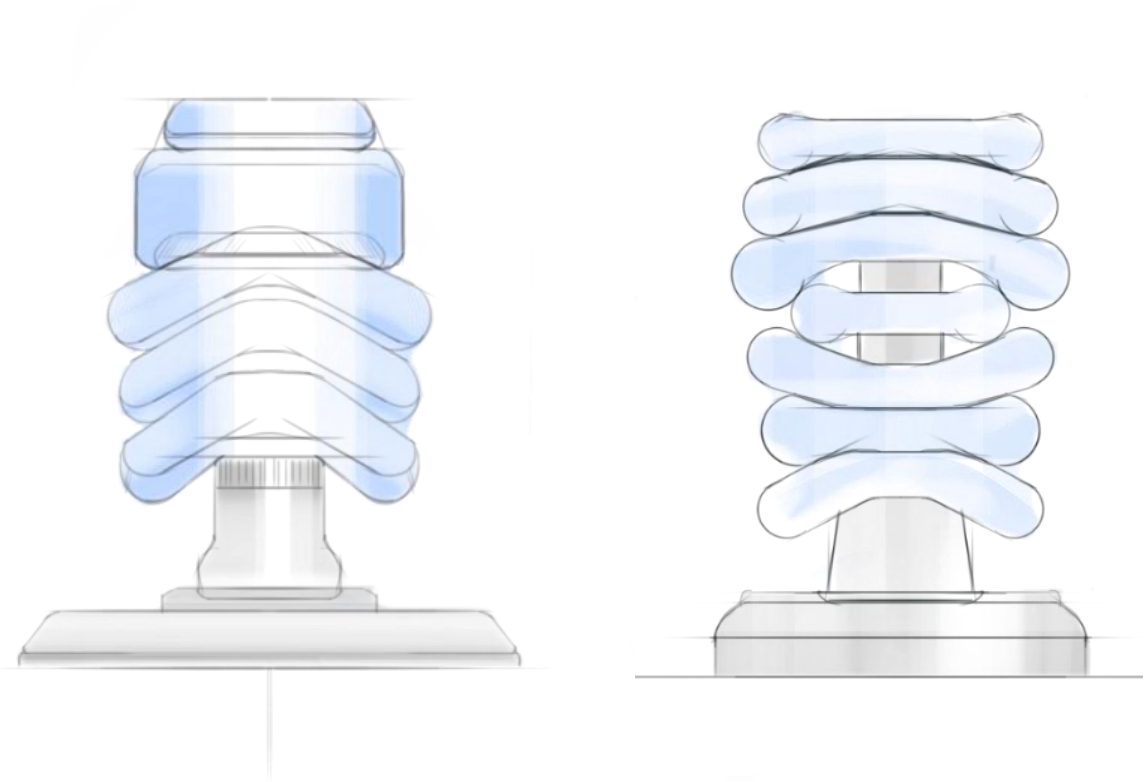


Figure 13 : Ideation Sketch

Children's imagination is usually affected by their surroundings. And, it attracts them when they see something from which they can connect and recognize from their past. Therefore, I tried to include some shapes which they see around like tress, conical caps, etc. This inspired me to look for the shapes of stackable chips which can form shapes like trees or other recognizable shapes.

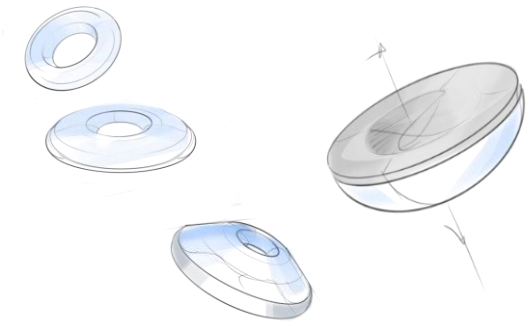


Figure 14 : Ideation Sketch (Chips)

Getting inspired by the toys and their design implementation, I tried to add the shape element of stars and sky which every child has to hear about in their night stories. They

can imagine a cloud and stars with musical notes which can also be seen in some of the children's cartoon books or videos.

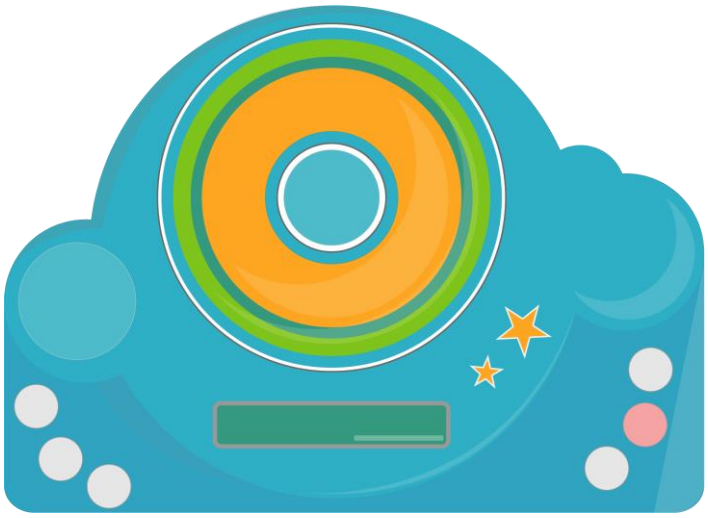


Figure 15 : Product illustration

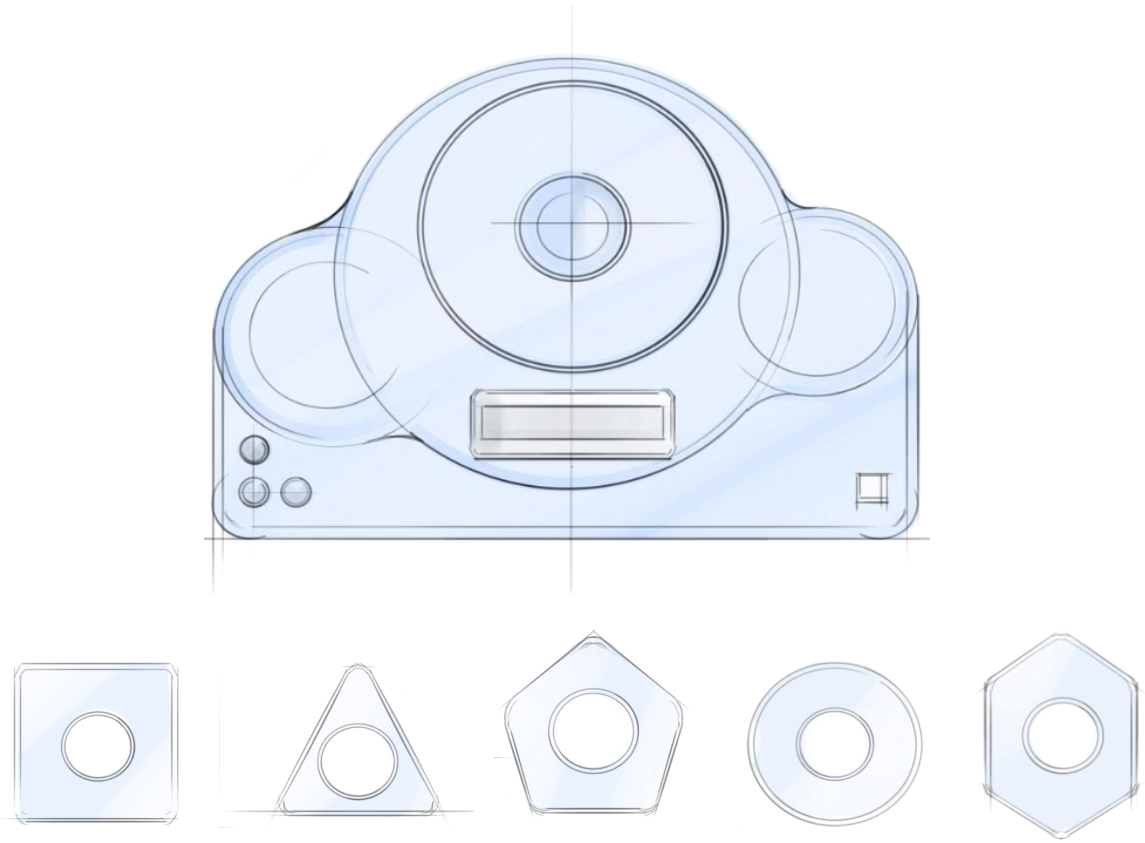


Figure 16 : Ideation Sketch

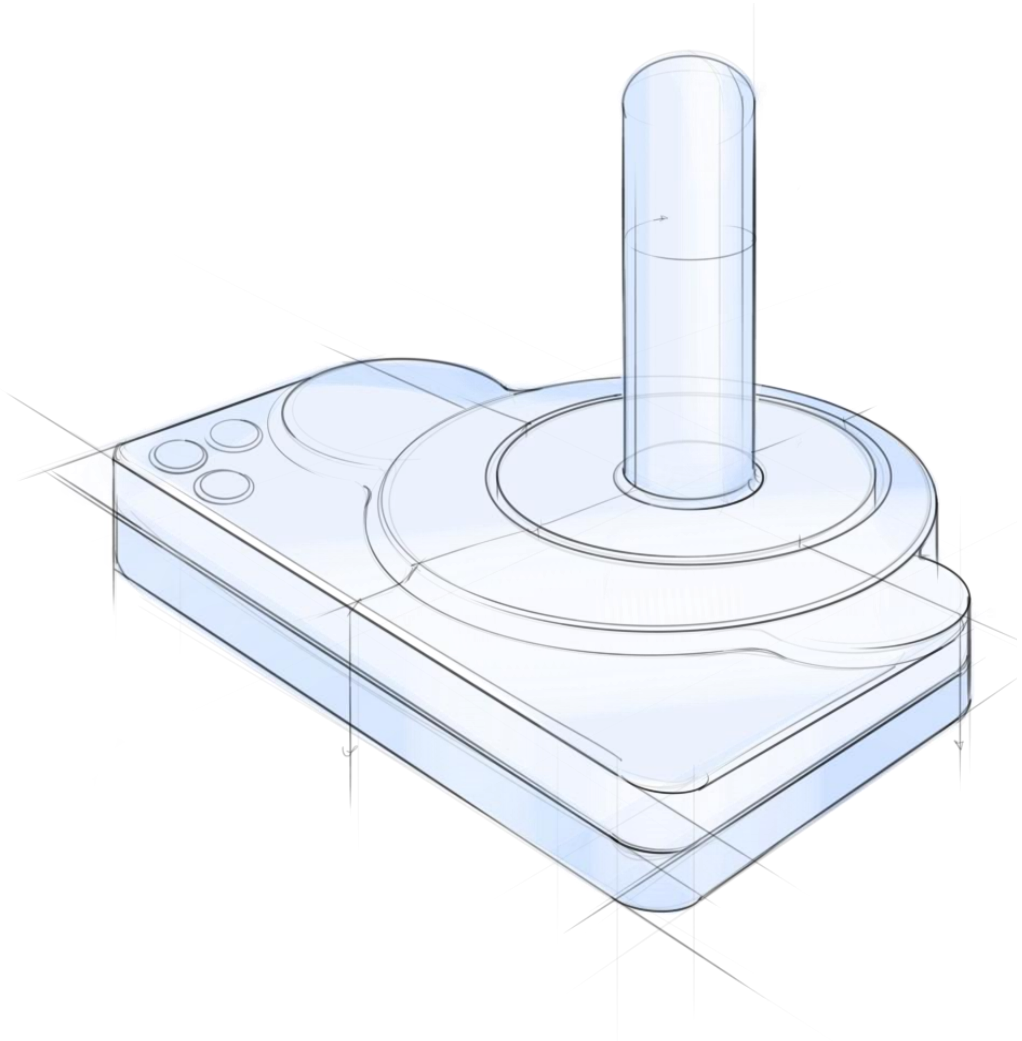


Figure 17 : Ideation Sketch

5.2.3 3D Visualization: After developing the shape It was important to understand needed space for the inner hardware. There are some components which needed to be exposed outside of the casing such as buttons and Arduino USB port. With considering some enough space for each hardware and wiring the device has dimension of 230mm x 190 mm x 40 mm (excluding the pole for ring which is 180 mm high). With all these dimensions, 3d model was made by using "SOLIDWORKS' Modelling software. Furthermore, to understand the aesthetics in terms of product color, surface, and material. Computer Rendering was done using the software "Keyshot" which was able to provide real world visualized product visuals which can be seen in below images:

Figure 18: PLAi board Visualization 01

Figure 19: PLAi board Visualization 02

5.3 Product functionalities

Based on the finding of the research of interactive technologies, toys, and therapies, I proposed some of the functionalities for the project to fulfill. According to these functionality sets, the Plai board is designed with using musical play to engage with children to provide therapy in the comfortable surroundings.

Free open play: Plai Board consists of the musical play where each chip has a dedicated musical note. This musical interface provides children audio sensory pleasure as they get musical feedback on each step or activity they perform with the toy. It also promotes musical understanding in the children. They learn creative thinking with musical notes. They can learn new ways to express through these musical notes audio which they can provide with each chip. It provides them an opportunity to use non-verbal expressions to exchange their feeling. Many therapeutic activities include music play in children's activities to release their stress, frustration, and mental pressure.

Motor skills development: Plai board integrates some motorized actions which are required for children to play the game. It is gamified with some sensory outputs which encourage to execution of some hand and eyes coordination actions. Each chip weighs differently. It gives them a change in force and effort in their hand movement which makes them practice their motor skills. While the chips can be added and donned on the product in one specific way by adding from the top. Thus, Children need to follow specific motions with precision to be collinear with the product in order to achieve the next step.

Cognitive Thinking: Gamification of Plai board includes choosing the right color chips according to the guided color in the instructive level of the game. This makes children make cognitive decisions. They need to understand the toy feedback then decide and perform the desired action which is adding the hinted color chip on the board in order to generate the intended musical note. On the other hand, in the open play

Color Recognition: Each chip is different in colors. These different colors can help them to remember which color have specific notes assigned to it. In the guided level of the game, the colors of chips play an important role for them to teaching them color and make them remember the name of the color with musical notes. This gamification can help children to learn colors and also shapes.

Creative Coding: Plai board allows children to create their own musical experience. They can create a musical tune with the addition of colorful chips. These chips can work as a code that can be stacked in a different arrangement in order to synchronize the notes for the tune. In each action of children, they receive a musical output from the

device. This encourages them to try new arrangements. Furthermore, they can create their own tune. Overall, this feature encourages the practice of creative activity. They learn to think and create new musical output

Engaging interface: Children have a very curious nature. When they see something new, and they engage in that but as soon as they find something newly interesting. They divert their attention toward the second thing. Therefore, the Plai board needed to have engaging property. This device tries to engage children and hold their attention by providing sensory feedback through music.

Limited game level: Some autistic children do have difficulty paying attention while other autistic children are able to keep their attention for a long period of time. In this case, it is difficult for them to disengage from the activity. And they show repetitive nature sometimes. This device tries to break this continuity in focus with a desirable amount by allowing them to restart the game with a different outcome. Once the child the tune then he or she can restart the creative step which can give a different tune.

Child-Parent Communication: This device has different levels of games which involves the creation of some audio output. Child and parents can create their own musical tunes and share them with each other. They can express their emotions through their creative activity in this device in order to reduce the child and parent communication gap.

Prototyping

6.1 Product working

Plai Board is an interactive game based on color music coding with musical audio output. It is based on the 7 basic musical notes which are assigned to 7 different color chips.

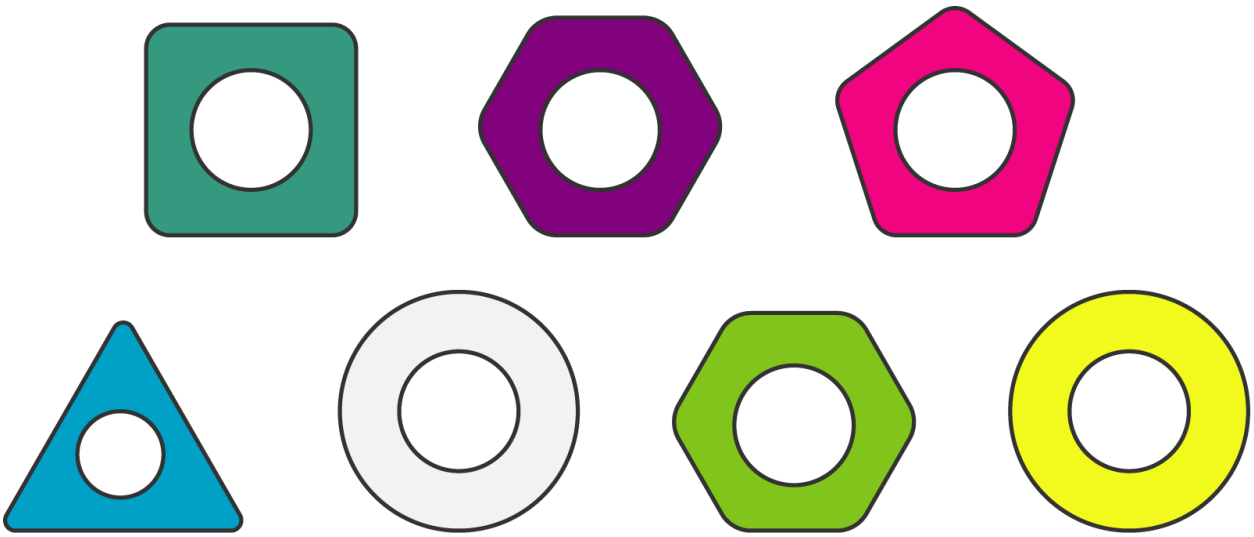


Figure 20 : Seven color chips

Plai board works as a musical coding machine for a child where they can create small basic musical tunes with the help of these chips. As described these chips have defined musical notes when these chips are added to the Plai board. It gives a sound of that specified musical note. Thus adding the chips in different combinations can allow children to generate their own musical notes combination.

Before both level selection in menu option, It is required to calibrate the device which can be done by parents or caretakers by adding one known weight which is informed on the LCD display of the prototype. For example, it can be seen in the prototyping stage, the device ask to put 100grams weight to calibrate the device.

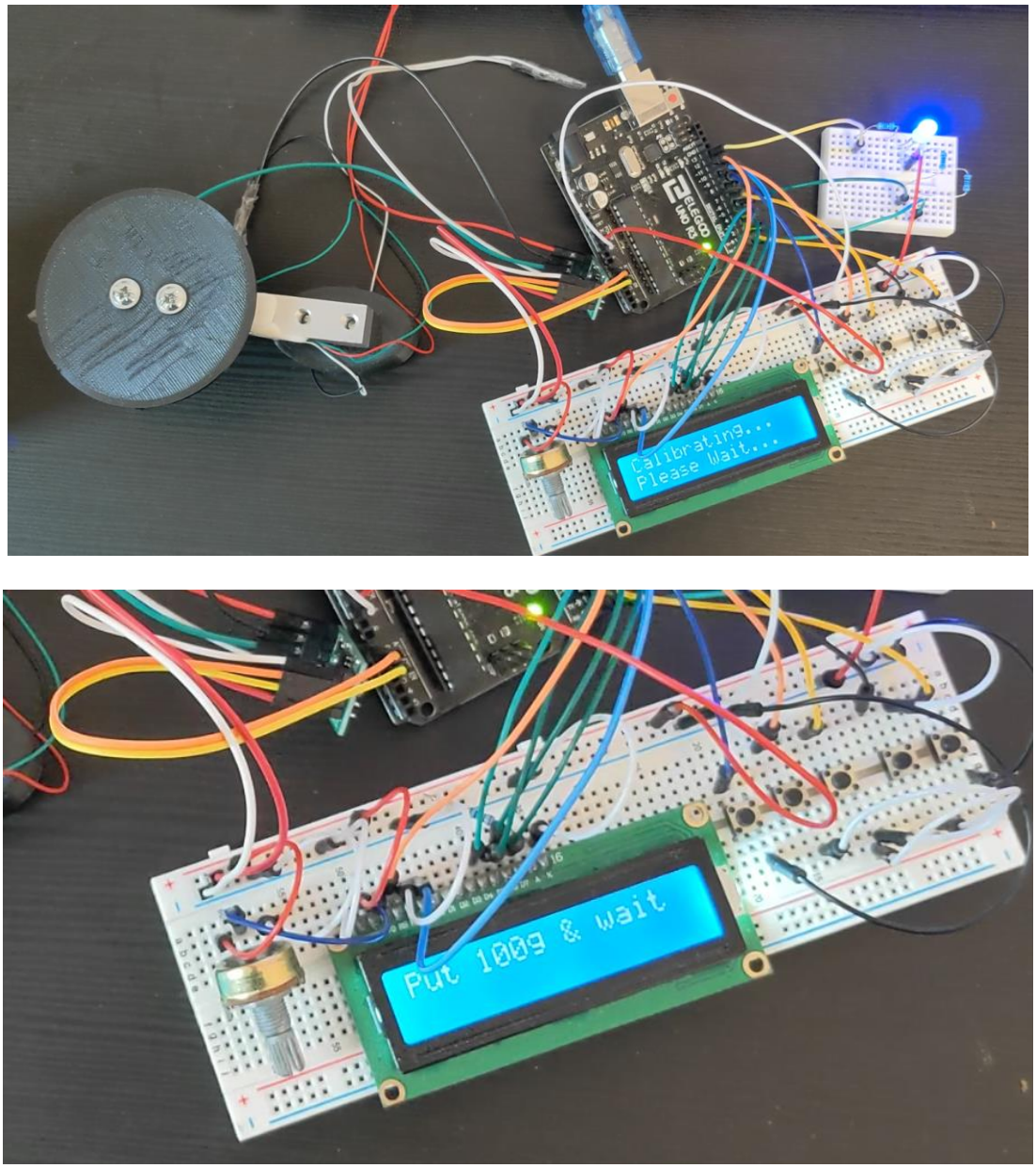


Figure 21 : Calibration weight input

This gamification is embedded in the device as two levels of play.

1. Color Learning
2. Free play Coding

Color Learning Level: This level of the game focuses on teaching autistic children about colors and shapes. It also makes them practice remembering skills because each color chip has its own distinctive musical note embedded within it. So, playing at this level, the

child can remember which color chip has a specific musical note. This also prepares the children for the free play of musical coding level.

This level involves the guidance by the device to generate a small portion of preset tunes such as Christmas tune composed of seven musical notes. When children choose to play this mode. Plai board guides the children to get this preset tune at the end of the level as a result of children's actions. This musical outcome encourages children to try new combinations as they can hear their creation in musical form.

For example in this stage, It shows two guided color learning levels available in the menu option to select:

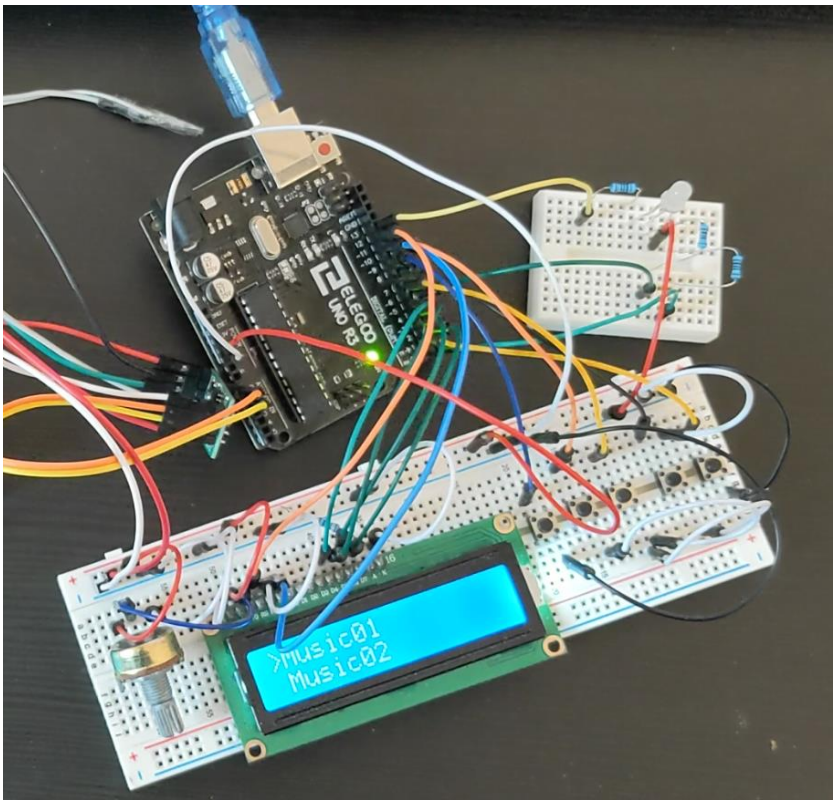


Figure 22 : Choosing Color Learning

The steps included in this level after the selection of the Guided play from the menu option are as

- After selecting the level, the device shows the color of the chip which needed to be added on the weight scale of the device in order to give an initial musical note of the present tune.
- As the correct chip is added, the device proceeds forward and plays the initially defined music note which was set up for added color chip.

- Now as a right chip was added to the device and correct output was given. The device lightens up the LED diode for the next color chip which needs to be added.
- When again the right chip is added according to the LED diode color, It recognizes it. And it provides desired preset note sound.
- This process goes on until the seventh chip to get the final musical note and when the end chip is added, the device plays the whole tune which was created by the children by adding chips throughout this level.

Free play coding: This level of the game focus on the development of the creative ability in autistic children. As children get aware of the colors and their relationship with the different musical notes. Here, they can practice creating different tunes according to their imagination. They can try their own combination of colors and express their feeling through these colors and musical notes. They can play these games with their parents where they can try to teach and show their creation of music through this toy.

This level involves free play. The device waits freely for a while to sense the color chip which will be added to the weight plate of the device. There is no guidance for chip addition at this level. Instead, the device prompts the LED color after the chip is added by recognizing the color. And Free play can be selected after guided music options. For example, in this stage, It shows free play levels available in the menu option to select:

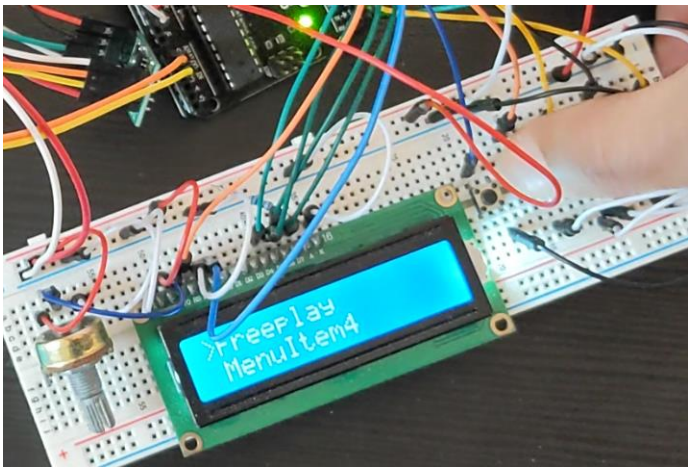


Figure 23 : Choosing Free play option

The steps included in this level after the selection of the free play from the menu option are as

- After selecting the level, the device waits for the color chip to be added.

- As soon the chip is added, it recognizes the color and shows the chip color on the LED diode in order to give a visual sense to children about chip color addition.
- Later showing the chip color on the LED diode, the musical note is played by the device which is assigned the added color chip.
- This process of addition of color chip, Showing the LED color of that added chip, and giving musical note output continues until seventh chip.
- At the end of the last chip addition or when the addition of the chip is stopped for 20 seconds, It automatically gives the final tune which is created by the child by the adding the color chips.

6.2 Hardware Specification

As the product working has been described, the whole operation of the device is a result of the combined work of hardware and software synchronization. All the peripheral components are interconnected with wires. It is composed of one microcontroller - Arduino Uno, weight sensing load cell, signal amplifier, DC Power source, 16x2 LCD Display, Speakers, and Potentiometer. They are defined in detail with their specifications and usage below:

Arduino UNO:

Arduino UNO is a low-cost, flexible, and easy-to-use programmable open-source microcontroller board that can be integrated into a variety of electronic projects. This board can be interfaced with other Arduino boards, Arduino shields, Raspberry Pi boards and can control relays, LEDs, servos, and motors as an output (Ashley, 2021). It can be programmed through various Integrated development environments (IDE) such as Arduino IDE, Visual studio VS Code, etc. generally based on the programming language C++ or C.

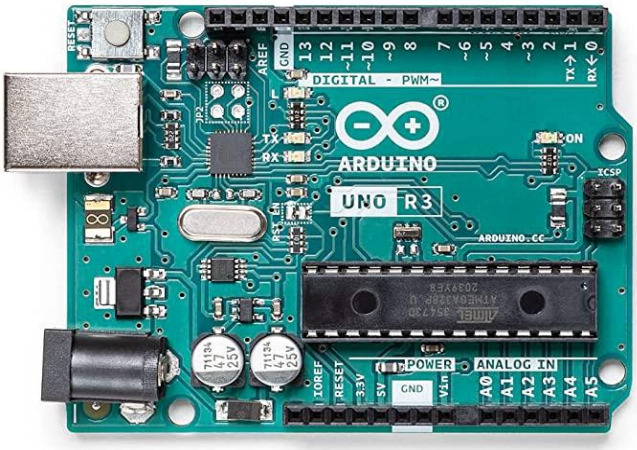


Figure 24 : Arduino UNO

The microcontroller board which is integrated into Arduino UNO is based on ATmega328, and Uno is an Italian term that means one. This board includes digital I/O pins-14, a power jack, analog i/ps-6, ceramic resonator-A16 MHz, a USB connection, an RST button, and an ICSP header. All these can support the microcontroller for further operation by connecting this board to the computer. The power supply of this board can be done with the help of an AC to DC adapter, a USB cable, otherwise a battery. It operates on 5V voltage and the recommended input voltage ranges from 7V to 12v. It has a flash memory of 32Kb which is enough for basic data storage. It embeds the CLK speed clock which operates on 16Mhz (El-Pro-Cus, n.d.).

It has some important pins which serve a different purpose and can be seen in this diagram shown below:

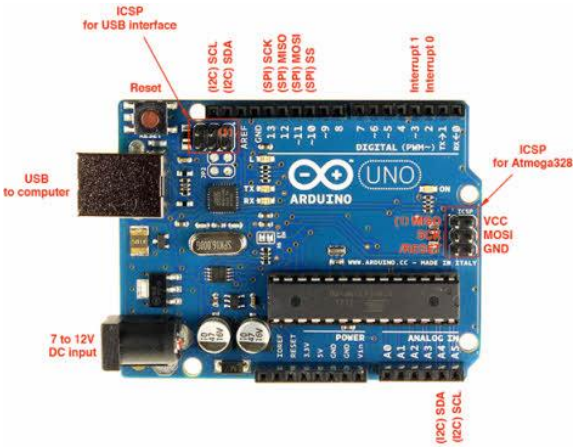


Figure 25 : UNO Pins description

In this project, I have programmed the Arduino Uno using Arduino provided IDE to define the core commands of principle operations. It has its own database library which can be found on Arduino community.

Load Cell Amplifier - HX711:

HX711 is a precision 24-bit analog to digital converter (ADC) designed for weigh scales and industrial control applications to interface directly with a bridge sensor. There is no programming needed for the internal register. All controls to the HX711 are through the pins (AVIA Semiconductors).

These pins include four input pins to read the reading from Wheatstone bridge of loadcell while other 4 pins are pins including one ground pin, one Voltage pin (usually 5V), One clock pin named SCK and one data pin named DT pin.

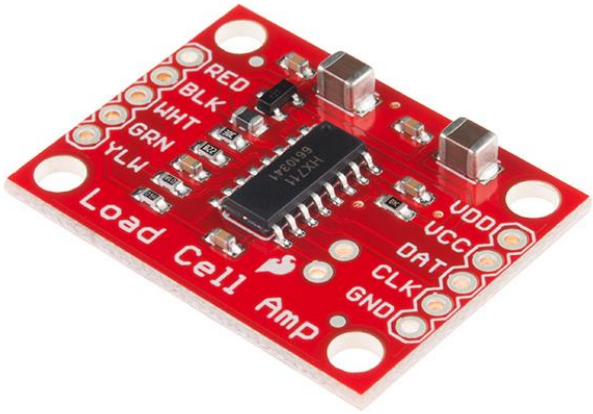


Figure 26 : Load Cell Amplifier - HX711

It is a load cell amplifier which also amplifies the signal received through load cell. It is a small breakout board for the HX711 IC that allows you to easily read load cells to measure weight. By connecting the amplifier to your microcontroller, you will be able to read the changes in the resistance of the load cell, and with some calibration you'll be able to get very accurate weight measurements. This can be handy for creating your own industrial scale, process control or simple presence detection. It is used in applications such as Weigh Scales, Industrial Process Control, etc (Sparkfun, n.d.).

Load Cell Sensor:

A load cell is an electronic sensor for measuring weight and force. When a force is applied to it, a weak electrical signal at the millivoltage level appears on its output wires. In fact, the load cell is a transducer which converts force into measurable electrical output.

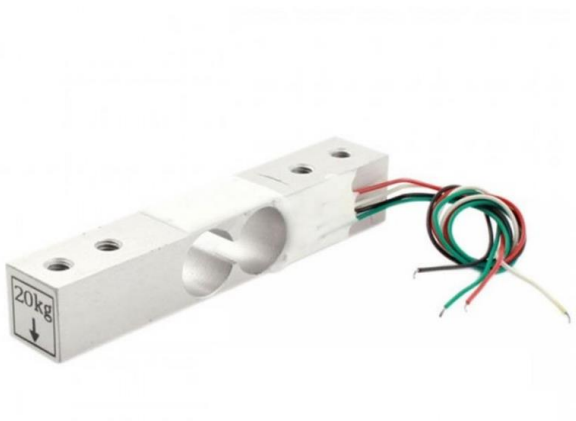
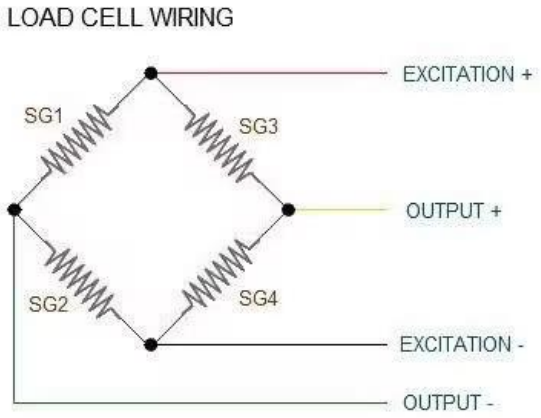


Figure 27 : Load Cell - 20 Kg

A load cell consists of a metal core and a set of electrical resistances that transform when a force is applied to it. But after the force is removed, it returns to its original state. The reversibility of this material determines the quality and accuracy of the load cell. The equivalent electrical circuit of a load cell is as follows:



Load cell have four wires based on the Wheatstone bridge:

- Red wire is for Excitation +
- Black wire is for Excitation -

- White for Output -
- Green wire is for Output +

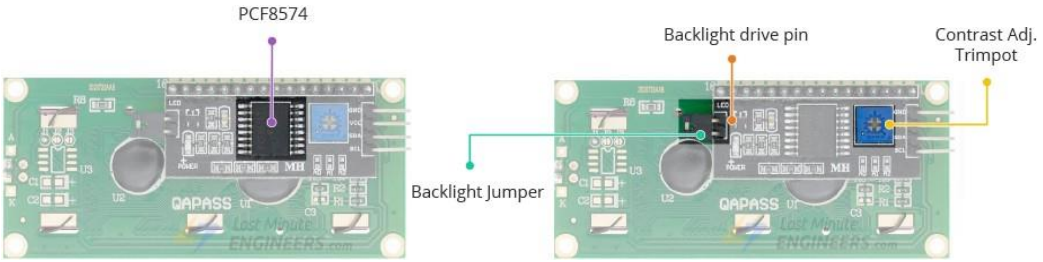
Change in between Output wire only affect the polarity of the reading (Peak, 2019).

LCD Screen:

Display used in this device is LCD screen with 16x2 display. It is cheap display available for Arduino Integration. A Liquid crystal display is a form of visual display used in electronic devices, in which a layer of a liquid crystal is sandwiched between two transparent electrodes. Here, I have used normal 16x2 liquid crystal display with i2c bus module (sharma, 2018).

Figure 28 : 16x2 LCD Display with I2C bus module

At the heart of the adapter is an 8-Bit I/O Expander chip – PCF8574. This chip converts the I2C data from an Arduino into the parallel data required by the LCD display. The board also comes with a small trim pot to make fine adjustments to the contrast of the display. In addition, there is a jumper on the board that supplies power to the backlight. To control the intensity of the backlight, you can remove the jumper and apply an external voltage to the header pin that is marked as 'LED' (lastminuteengineers, n.d.).



I2C combines the best features of SPI and UARTs. With I2C, you can connect multiple slaves to a single master (like SPI) and you can have multiple masters controlling single, or multiple slaves. This is useful when you want to have more than one microcontroller logging data to a single memory card or displaying text to a single LCD.

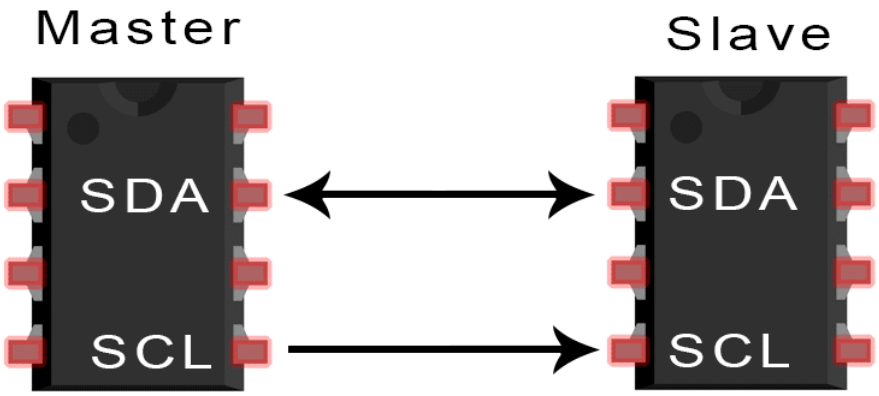


Figure 29 : I2C Bus data flow between SDA and SCL channels

Potentiometer:

A potentiometer is a manually adjustable variable resistor with 3 terminals. Two of the terminals are connected to the opposite ends of a resistive element, and the third terminal connects to a sliding contact, called a wiper, moving over the resistive element. The potentiometer essentially functions as a variable resistance divider. The resistive element can be seen as two resistors in series (the total potentiometer resistance), where the wiper position determines the resistance ratio of the first resistor to the second resistor. If a reference voltage is applied across the end terminals, the position of the wiper determines the output voltage of the potentiometer.

Rotary Potentiometer

Figure 30 : Rotary Potentiometer

In the device, I have used a potentiometer to adjust the voltage for LCD display input. This adjustable function, it allows me to adjust the LCD display brightness. The potentiometer was only during the prototyping stage where I was using LCD which did not have an integrated I2C bus module (EE Power, n.d.).

DC Battery Power Source:

During the trial phase of the prototype, I have used the USB cable to power the Arduino UNO circuit. As I progressed from initial prototyping to finalizing the prototype, I preferred to attach an external power source which makes the device more portable and independent of the computer. For this purpose, I used a battery to provide DC current. Arduino UNO board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

Using 9V is usually a preferred choice of voltage. You can simply connect the + end of your battery to Arduino Vin and the - end to Arduino ground. You should see the green light on the Arduino turn on to indicate that it is powered.

Figure 31 : 9 volts DC Battery attachment for Arduino UNO

8-Watt Round Speakers:

Small 8-watt speakers were used to audio output. These speakers can be attached to the Arduino without any resistors or any other peripheral part. The positive sign terminal is attached to the Arduino pins while the negative end terminal is always attached to the ground. The circular dimension of these speakers is 36 mm Diameter. I used two speakers in this device.

Figure 32 : 8 Watt Speaker

LED Diodes:

LED diodes are light-emitting diodes used for electronics. They consume very less energy and provide excellent efficiency. In this device, the LED diode is used to show the color chips recognition by the load cell. LED can be of one color and multiple colors output. I have used here RGB color LED. This is one LED integrating 3 LEDs property (RED, Green, Blue). Thus, by combining these primary colors RBG LED can create different colors.

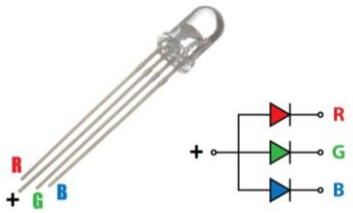


Figure 33 : LED diodes

6.3 Software Implementation

Arduino UNO has its own integrated development environment tool for the development of the programming code. It also further allows to compile and run the written program. To create a program for the device, this Arduino IDE was used. The code was created in several steps to ease the process of development and also to debug when any problem exists.

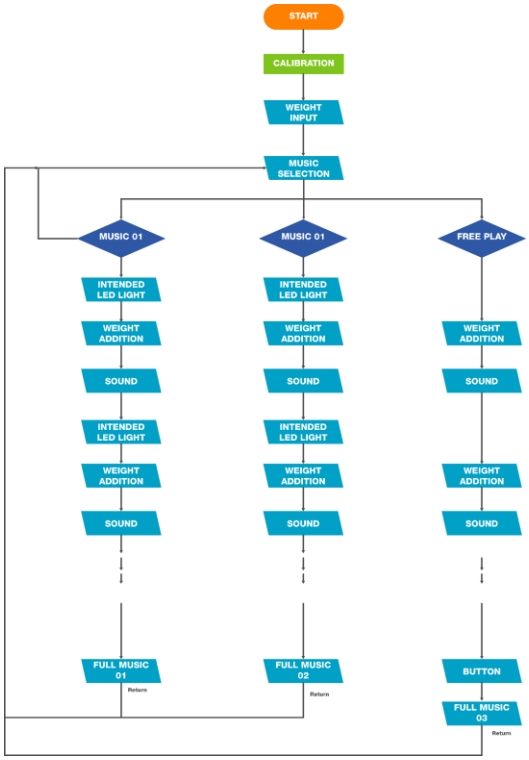


Figure 34 : Programming flow chart

The program is divided into substructures such as

- Weight Measurement

- Integration of LCD display
- Menu Setup Integration
- Adding and combining LED function with weight recognition
- Adding Audio output and combining it with weight recognition

Weight Measurement:

The first step for the device was to recognize the weight which is put over the load cell. This program can be defined as a base of all the programming for the device. There are load cell and load cell amplifier (HX711 chips) components which contribute to weight measurement. It was required to define all the pin connections of these weight measuring components.

```
#define DT A0
#define SCK A1
#define sw 9
```

After defining the pins, HX711 have library in open-source platform. Therefore, it was not required for me write the instruction whole calibration mode. However, it was necessary to define the library with all the variables which is important in this context. And, using the function for calibration, there was calculation to bring the load cell pre-loaded deflection to zero. To do that, initial deflection as "read count" taken and then subtracted till 0 value by trial and error method of giving different values.

```
void calibrate()
{
lcd.clear();
lcd.print("Calibrating...");
lcd.setCursor(0,1);
lcd.print("Please Wait...");
for(int i=0;i<100;i++)
{
count=readCount();
sample+=count;
}
sample/=100;
lcd.clear();
```

```
lcd.print("Put 100g & wait");
count=0;
while(count<1000)
{
count=readCount();
count=sample-count;
}
lcd.clear();
lcd.print("Please Wait....");
delay(2000);
for(int i=0;i<100;i++)
{
count=readCount();  // for condition to execute reading till desired iutput
val+=sample-count;
}
val=val/100.0;
val=val/100.0;    //    put    here    your    calibrating    weight
lcd.clear();
}
```

Addition of weight calculating function: As soon I was able to get calibrated reading corrected. I added the measurement formula to get the corrected reading of the load cell. This reading was added in loop function, as it needed to keep updating the weight change for the device.

```
count= readCount();
int   w=(((count-sample)/val)-2*((count-sample)/val));   //   Formula derived    to    reach    correct    value    of    the    weight
lcd.setCursor(0,0);
lcd.print("Measured  Weight");  //  Measured  weight  print  command
lcd.setCursor(0,1);
lcd.print(w);
lcd.print("g ");
```

While, there is another function called "tare" can be used to command the weight calibration and load cell reading. However it separated the process of calibration and weight reading process.

Integration of LCD Module:

After the getting the weight outcome form load cell, I needed to integrate the LCD display in the device. In pathotyping stage, I was using Arduino IDE serial port to visualize and to get the output of loadcell. But, it is essential to show all the output on the display. For this purpose, I tried two type of LED module. One LED module had potentiometer added manually in order to adjust the brightness of the display while other LED module has less wires, has potentiometer integrated in its module and also has I2C bus module to data transfer.

Defining the librarey and pins for the microcontroller to understand the data flow:

For LCD with added potentiometer, I had to add <LiquidCrystal.h> library from arduino database,

```
#include <LiquidCrystal.h>
const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
```

For LCD with integrated potentiometer and I2C bus , I had to add two different library <Wire.h> and <LiquidCrystal_I2C.h> from Arduino database, with defining the pins connections.

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27, 20, 4);
```

While all the data was printed with the following commands;

```
lcd.begin(16, 2); // Initializing the LCD
lcd.print(" Weight "); // print command
lcd.setCursor(0,1);  // Line change in display
```

```
lcd.print(" Measurement ");
```

Menu Setup Integration:

The device have some levels integrated in the two level. One is guided play to make children aware about the game while another level is free play where children can play freely. Therefore, I tried to include menu function for the device.

However, the first step was to define all the buttons which were necessary to navigate in the menu:

// Defining pins for Menu buttons

```
int upButton = 10;       // Up Button
int downButton = 7;       // Down Button

int selectButton = 8;       // Select Button

int menu = 1;       // Back to Menu Button
```

In the menu programming, there were three functions added which sub-divided into three sections: Updatemenu(), executeaction(), Menunavigation() which is set to be in loop condition.

```
//loop call for "MENU NAVIGATION"------------------------------
-----//

  if (!digitalRead(downButton )) {
    menu++;
    updateMenu();
    delay(100);
    while (!digitalRead(downButton));
  }
  if (!digitalRead(upButton)) {
    menu--;
```

```
    updateMenu();
    delay(100);
    while (!digitalRead(upButton));
  }
  if (!digitalRead(selectButton)) {
    executeAction();
    updateMenu();
    delay(100);
    while (!digitalRead(selectButton));
  }
```

```
// Function defining instruction for Update Menu function

void updateMenu() {
  switch (menu) {
    case 0:
      menu = 1;
      break;
    case 1:
      lcd.clear();
      //lcd.print(">MenuItem1");
      lcd.print(">Music01");
      lcd.setCursor(0, 1);
      //lcd.print(" MenuItem2");
      lcd.print(" Music02");
      break;
    case 2:
      lcd.clear();
      //lcd.print(" MenuItem1");
      lcd.print(" Music01");
      lcd.setCursor(0, 1);
      //lcd.print(">MenuItem2");
      lcd.print(">Music02");
      break;
    case 3:
      lcd.clear();
```

```
      //lcd.print(">MenuItem3");
      lcd.print(">Freeplay");
      lcd.setCursor(0, 1);
      lcd.print(" MenuItem4");
      break;
    case 4:
      lcd.clear();
      //lcd.print(" MenuItem3");
      lcd.print(" Freeplay");
      lcd.setCursor(0, 1);
      lcd.print(">MenuItem4");
      break;
    case 5:
      menu = 4;
      break;
  }
}
```

Further to insert each action on the menu selection, I had to add action functions which command the device to play or turn On the LED diodes according to the inserted weight.

```
void executeAction() {
  switch (menu) {
    case 1:
      action1();
      break;
    case 2:
      action2();
      break;
    case 3:
      action3();
      break;
    case 4:
      action4();
      break;
```

```
  }
}

void action1() {
  lcd.clear();
  //lcd.print(">Executing #1");
  lcd.print("FOLLOW STAR");
  lcd.setCursor(0, 1);
  lcd.print("COLOR ");
```

Assigning LED color diodes for specific weight output:

LED diodes works as a visual feedforward on this device. It informs the children what to do next and can be integrated with results to give different feedback. Till now, I was able to manage to combine the menu navigation program in the base program which allowed me to have selection in two different levels in the game.

```
// Defining pins for LED bulb

int red_light_pin = 0;
int green_light_pin = 6;
int blue_light_pin = 13;
```

After defining the Pins and the LED diode wiring, I added one LED function defining same colors as respective to the chips. The color was based on LED diode RBG values which such as :

```
Colors RGB Cobinations --------------------------

            RGB_color(255, 0, 0); // Red
          delay(1000);
          RGB_color(0, 255, 0); // Green
          delay(1000);
          RGB_color(0, 0, 255); // Blue
```

```
          delay(1000);
          RGB_color(255, 255, 125); // Raspberry
          delay(1000);
          RGB_color(0, 255, 255); // Cyan
          delay(1000);
          RGB_color(255, 0, 255); // Magenta
          delay(1000);
          RGB_color(255, 255, 0); // Yellow
          delay(1000);
          RGB_color(255, 255, 255); // White
          delay(1000);
```

While, in order to display these color according to the supposedly added color chip. There was a small function and command used to guide this function which was :

```
void RGB_color(int red_light_value, int green_light_value, int
blue_light_value)
        {
          analogWrite(red_light_pin, red_light_value);
          analogWrite(green_light_pin, green_light_value);
          analogWrite(blue_light_pin, blue_light_value);
        }
```

```
RGB_color(255, 0, 255);  //MAGNETA
```

Embedding Musical Notes:

Musical notes were added as a final function to the program. There are some libraries available on programming database of online community which contains executing instructions of different musical notes and to use these libraries, I needed to define all notes in different program file and then recall it as my local library.

```
// Defining all the musical notes
#include "pitches.h"
```

Further to connect every note with specific color recognition and weight measurement, I needed to use array function of the programming language because I was having more than one variable to decide the final musical note.

Additionally, this game has two levels. Thus, I had to use array functionality twice with different structure to execute separately.

To call the musical note function, I added simple function to play and define the particular notes with different pitch for each level:

int free_melody[] = {

```
  0, NOTE_C4, NOTE_C3, NOTE_D2, NOTE_C3, NOTE_B4, NOTE_A3, NOTE_A4
};

int sequence[] = {-1, -1, -1, -1, -1, -1, -1, -1};
```

First level of game which consist mankind aware of the children about the game and its color recognition and musical feedback has done using this array structure:

```
const int weights[] = {0, 15, 55, 115, 195, 295, 425, 580};
const int tolerance = 10;
const char *colours[] = { "BLACK","RED", "GREEN", "BLUE", "YEllOW",
"WHITE", "CYAN", "MAGNETA"};
const int color_code[8][3] = {{0,0,0}, {0, 0, 255}, {0, 255, 0},
{255, 0, 0}, {0, 255, 255}, {255, 255, 255}, {255, 255, 0}, {255, 0,
255}};
```

```
// Function to execute the preset musical level
    int w = 0;
    int index = 0;
```

```
    int seconds = 0;
    while(index < 8) {
      if(w >= weights[index]-tolerance && w <=
weights[index]+tolerance) {

      int noteDuration = 1000 / noteDurations[index];
        tone(A2, melody[index], noteDuration);
        // to distinguish the notes, set a minimum time between them.
        // the note's duration + 30% seems to work well:
        int pauseBetweenNotes = noteDuration * 1.30;
        delay(pauseBetweenNotes);
        // stop the tone playing:
        noTone(A2);



        index++;
        RGB_color(color_code[index][0], color_code[index][1],
color_code[index][2]); // Red

        //lcd.clear();
        //lcd.print(">Executing #1");
        lcd.print(colours[index]);
        lcd.setCursor(0, 1);
        lcd.print("RING ");
        delay(5000);
      }

      if(index>=8){
        for(int thisNote=0; thisNote < 8; thisNote++) {
          int noteDuration = 1000 / noteDurations[thisNote];
          tone(A2, melody[thisNote], noteDuration);
          // to distinguish the notes, set a minimum time between
them.
          // the note's duration + 30% seems to work well:
          int pauseBetweenNotes = noteDuration * 1.30;
          delay(pauseBetweenNotes);
          // stop the tone playing:
          noTone(A2);
        }
```

While for the second level of the game where children can play freely. It was necessary to add the color sequence and musical output depending on the random weight measurement rather than any preset weight input. It was achieved with different array defining and function:

```
const int free_weights[] = {0, 15, 40, 60, 86, 100, 125, 153};
const char *free_colours[] = { "BLACK","RED", "GREEN", "BLUE",
"YEllOW", "WHITE", "CYAN", "MAGNETA"};
const int free_color_code[8][3] = {{0,0,0}, {0, 0, 255}, {0, 255, 0},
{255, 0, 0}, {0, 255, 255}, {255, 255, 255}, {255, 255, 0}, {255, 0,
255}};
int free_melody[] = {

  0, NOTE_C4, NOTE_C3, NOTE_D2, NOTE_C3, NOTE_B4, NOTE_A3, NOTE_A4
};

int sequence[] = {-1, -1, -1, -1, -1, -1, -1, -1};
```

```
// Function to execute the freeplay musical level

 int w = 0;
    int counter = 0;
    int index = 0;
    int seconds = 0;
    while(true) {
      if(w>0&&w > pre_weight+tolerance && counter < 8) {
        current_weight = w - pre_weight;
        index = getIndex(current_weight);
        sequence[counter] = index;
        pre_weight = w;
        // last_weight = free_weights[index];
        int noteDuration = 1000 / noteDurations[index];
        tone(A2, melody[index], noteDuration);
        // to distinguish the notes, set a minimum time between them.
        // the note's duration + 30% seems to work well:
        int pauseBetweenNotes = noteDuration * 1.30;
        delay(pauseBetweenNotes);
        // stop the tone playing:
```

```
        noTone(A2);


        counter++;
        RGB_color(free_color_code[index][0],
free_color_code[index][1], free_color_code[index][2]); // Red

        //lcd.clear();
        //lcd.print(">Executing #1");
        lcd.print(*free_colours[index]);
        lcd.setCursor(0, 1);
        lcd.print("RING ");
        delay(5000);
      }

      if(counter>=7){
        for(int thisNote=0; thisNote < 8; thisNote++) {
          int noteDuration = 1000 / noteDurations[thisNote];
          tone(A2, free_melody[sequence[thisNote]], noteDuration);
          // to distinguish the notes, set a minimum time between
them.
          // the note's duration + 30% seems to work well:
          int pauseBetweenNotes = noteDuration * 1.30;
          delay(pauseBetweenNotes);
          // stop the tone playing:
          noTone(A2);
        }
        break;
      }

      lcd.clear();
      count = readCount();
      w = (((count - sample) / val) - 2 * ((count - sample) / val));
      lcd.setCursor(0, 0);
      lcd.print("Measured Weight");
      lcd.setCursor(0, 1);
      lcd.print(current_weight);
      lcd.print("g ");
      //delay(3000);
      delay(1000);
      seconds += 1;
```

```
      if(seconds > 200) {
        RGB_color(free_color_code[0][0], free_color_code[0][1],
free_color_code[0][2]);
        return; }
    }
```

With all these primary commands, I was able to achieve the desired function of the device. However, there was some limitation in programming IDE support for the Arduino UNO which will be discussed below in product limitation description.

6.4 Product Development:

6.4.1 Development of 3D model:

The device structure was modelled by considering the Design for Manufacturing and Assembly (DFMA). The main structure of the devices was designer while following some manufacturing rules which are suitable for injection molding process. The manufacturing process seems fulfill the manufacturing criteria can be injection molding process for mass production. Considering this condition, some manufacturing techniques were followed such as:

Draft Angle: In molding and drawing the products from mold, It required to have some slanted surface instead of vertical surface. Walls parallel to the mold or die can obstruct the product extraction. Therefore, these side walls have given little angle to allow easy removal of product from Mold or die. Usually in model parts, the draft angle ranges from 0.5 to 5 degree.

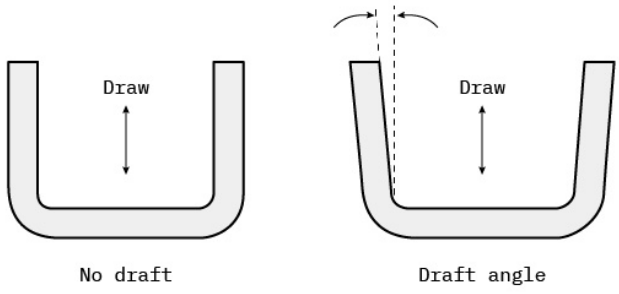


Figure 35 : Draft Angle

Ribs and Bosses: Ribs are an important feature in injection molding. Ribs allow to strengthen the structure of the component without increasing the wall thickness. A typical boss is an open-topped cylinder, essentially a round rib. If your design requires more strength than this guideline would provide, you should consider ways to strengthen the boss without thickening its walls. The most common of these is to surround the boss with gussets to support and strengthen its walls.

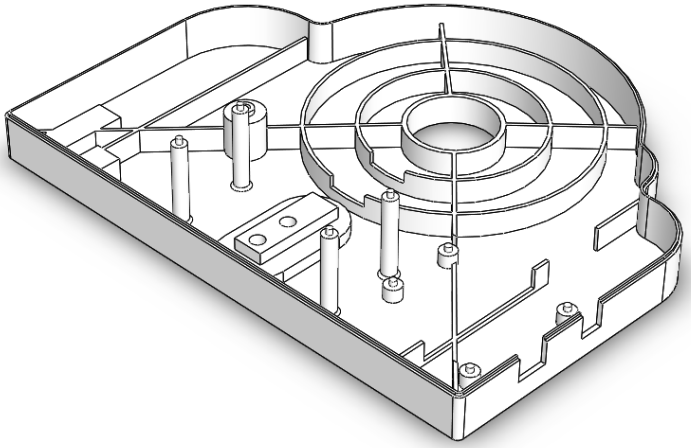


Figure 36 : Ribs and Bosses

Filleting Edges and Radii: Sharp corners are the some of the primary cause of part failure, stress concentrations, poor flow patterns and increased tool wear. Sharp corners should always be avoided. Fillet radius should be 25-60% of nominal wall thickness. Avoids stress concentrations. It helps keep uniform wall thickness and avoid stress concentrations. Inside radius = 0.5 x wall thickness. Outside radius = 1.5 x wall thickness.

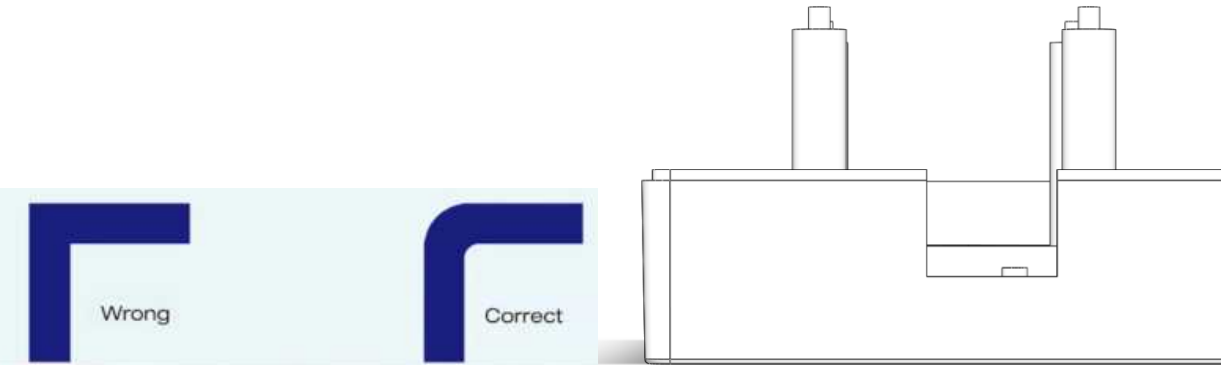


Figure 37 : Curved edges

The shapes which were ideated for the device were developed through 3D printing technology for the purpose of prototyping. Although for the product prototyping different forms of rules were used to develop the physical model of the plai board. The model includes two parts of the shell:

Figure 38 : Upper shell

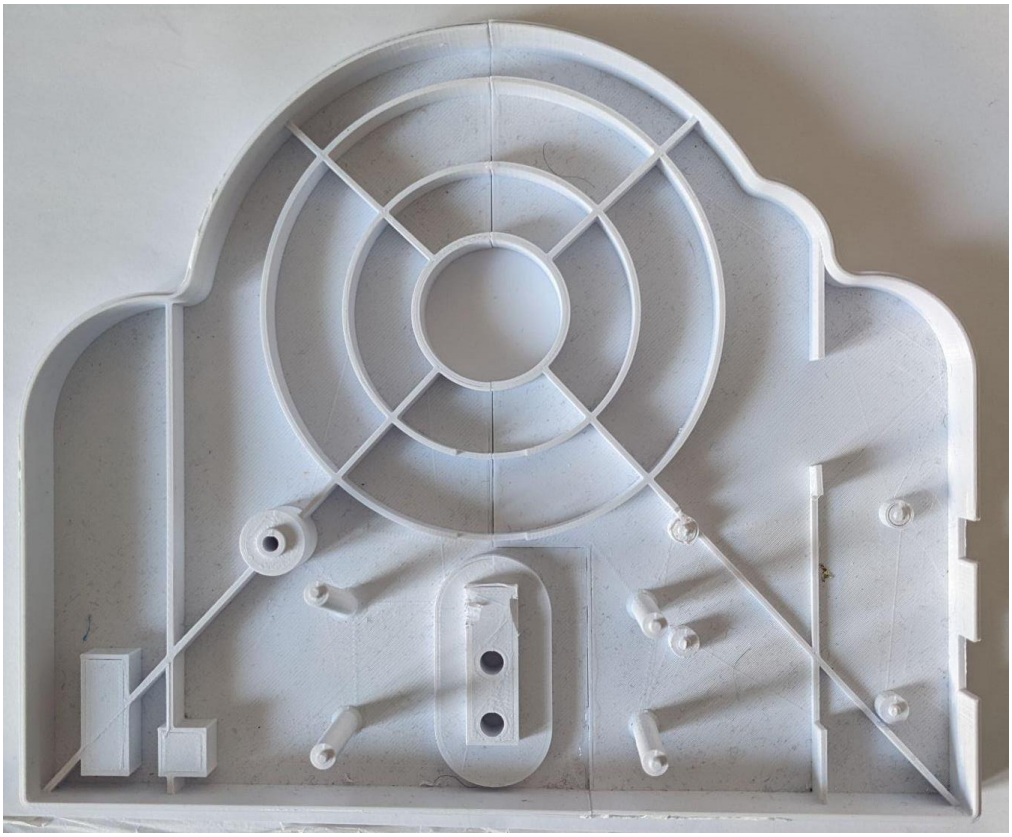


Figure 39 : Bottom shell

There were some extra peripheral components that were 3D printed to support the accessibility for the user about the device such as Buttons. While extra support bodies to support the weight-bearing platform.

Figure 40 : Support plate and Buttons

6.4.2 How electronic components are connected:

The prototype of the device was first made on a Prototyping kit. As It was discussed in the hardware implementation, Arduino Uno is being used as a microcontroller that

processes all the data for the device. The connection between the electronic components was made through jumper wires and the soldering process. It can be divided into several steps:

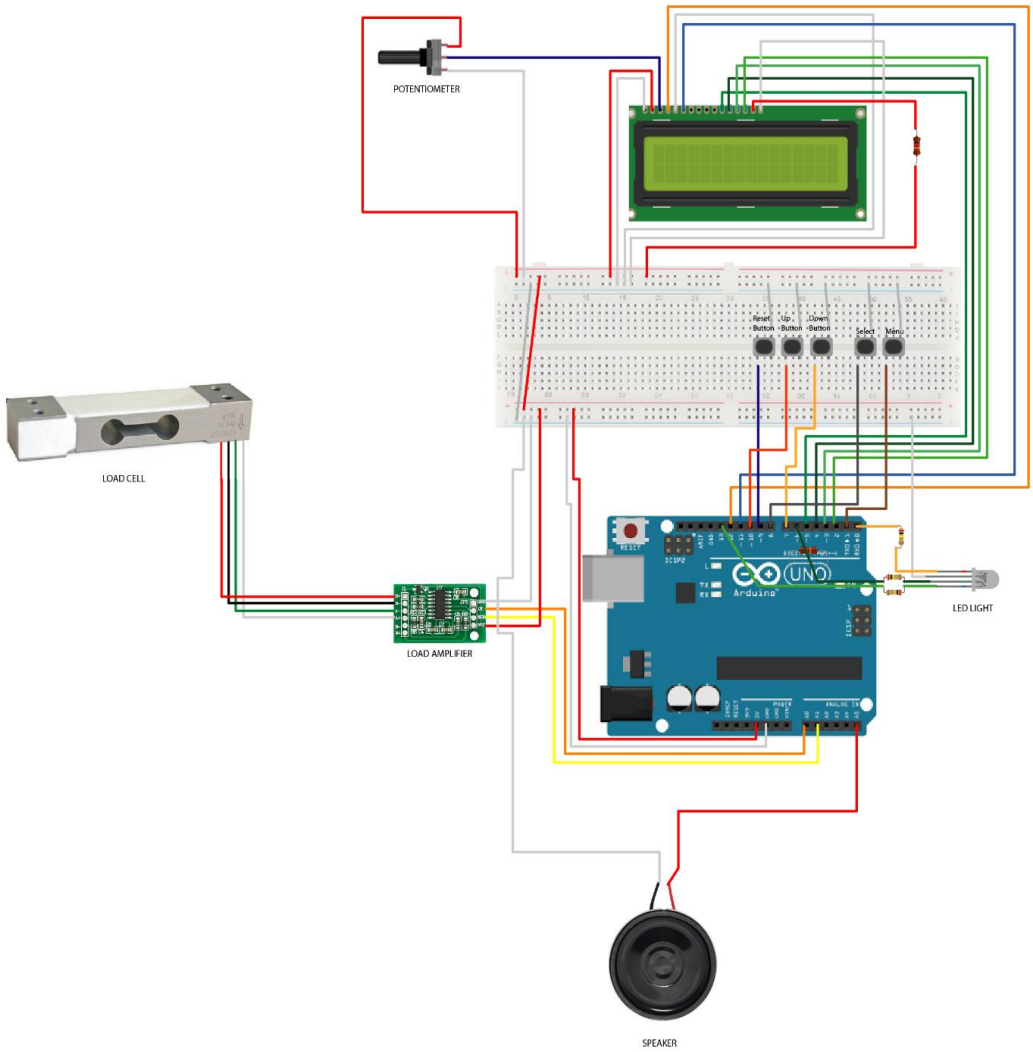


Figure 41 : Hardware wiring

Load Cell connections: The load cell is the base sensor that gives principal data to the microcontroller. It was first mounted on the Bottom shell of the Plai Board and its wires were connected to the Load cell amplifier (HX711). Load cells have embedded thread in them and can be connected to premade mounting through M4 bolt fasteners.

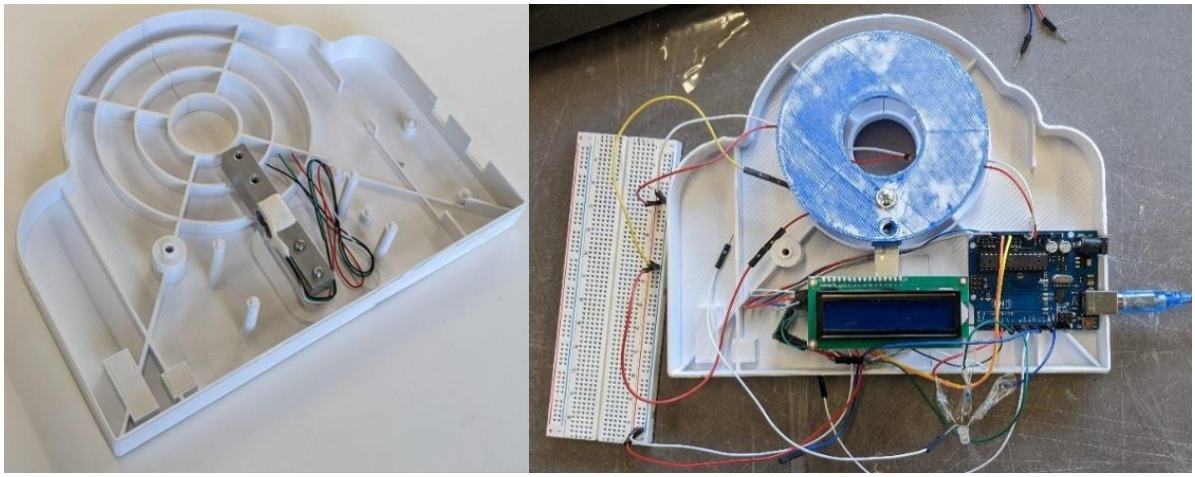
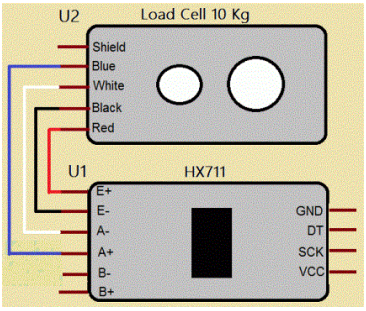


Figure 42 : Component mounting

Four outputs of the loadcell can be connected to the load cell amplifier in a manner shown below:



With combining all the available electronic components through jumper wire, I was able to achieve full system of internal hardware. I did some soldering to form the ground lane and voltage lane to convert my prototype form breadboard base to permanent proto chip. These internal components were well fitted over the 3D printed casing.

Figure 43 : Plai Board Shell Assembled

Figure 44 : Final assembly

6.4.3 Chips machining

Chips are machined on wood. Wood was used because of its lightweight, easy to shape, and texture properties. I was able to obtain the desired shape and desire weight difference in wooden chips after machining them on a drilling machine, Mechanical cutter, etc. Chips are also carved in different basic shapes in order to assist the children to remember the chips also by shapes as well.

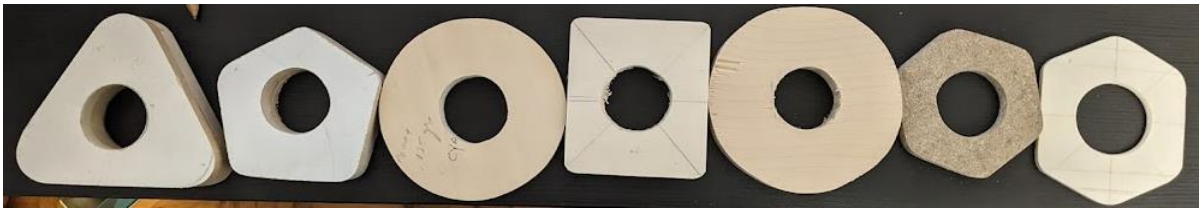


Figure 45 : Machined Wooden Color chips

6.5 Product Limitation:

Plai Board is an interactive toy which has very minimal function in the direction of gamifying the learning of basic skills for autistic children. It is made up of very basic hardware which are intended to be used for small project. Therefore, they restrict its feature. On the hand, the cost of the devices was also considered to have less function as one of the goals of the device was provide some therapy supporting accessory which parents can buy for their autistic children.

In terms of hardware, it does contain Arduino as Microcontroller as it can be operated through binary instructions. But it lacks in working memory and easy support for database in term of programming instruction. Other limiting constraint is that this microcontroller can only perform task at a time which restriction to add more parallel functional activities.

The device does not work on any AI or bot assistance. It has very basic interaction in term of functioning. It does not take voice and gesture input from the user.

The toy has limited interaction which is about giving basic feedback of audio and visual. Audio was limited to basic musical notes as it was store in a database rather than adding extra sensors.

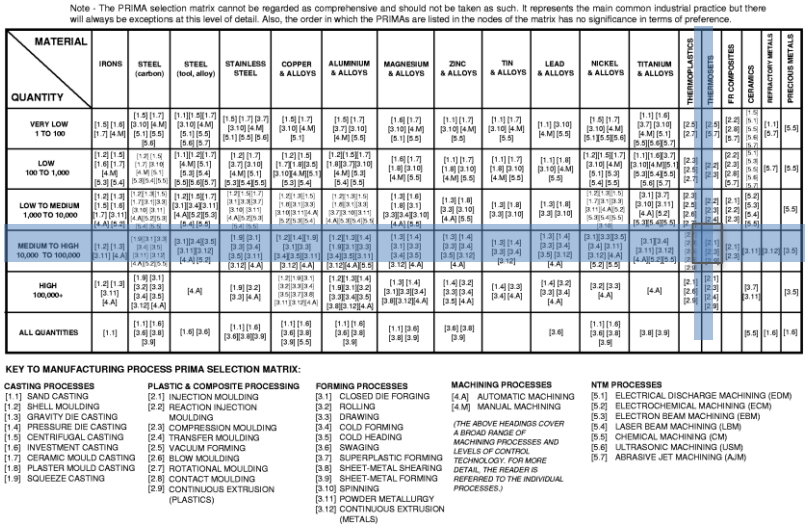
6.6 Cost Analysis:

During the development stage of the Plai Board, I have also considered the cost of the product. The main structure of the Plai Board is manufactured by ABS plastic while chips can be considered as buying supplies. There are many external suppliers which specialized in the wooden block manufacturing and can provided cheaper machining for these kinds of basic shapes.

Figure 46: Component of Shell

For cost estimation, I used the Ansys Granta CES Edupack library which have database of several materials and processing processes. Through the use of CES Edupack, I added all the parameters which can be considered in order to get profitable production of this device.

Amount of the device which will be produced in a year is considered to be 10000 units. By considering this number of units, I also referred "PRIMA Matrix table" to understand the best selection of manufacturing process.



Note - The PRIMA selection matrix cannot be regarded as comprehensive and should not be taken as such. It represents the main common industrial practice but there will always be exceptions at this level of detail. Also, the order in which the PRIMAs are listed in the nodes of the matrix has no significance in terms of preference.

MATERIAL / QUANTITY	IRONS	STEEL (carbon)	STEEL (tool, alloy)	STAINLESS STEEL	COPPER & ALLOYS	ALUMINIUM & ALLOYS	MAGNESIUM & ALLOYS	ZINC & ALLOYS	TIN & ALLOYS	LEAD & ALLOYS	NICKEL & ALLOYS	TITANIUM & ALLOYS	THERMOPLASTICS	THERMOSETS	FR COMPOSITES	CERAMICS	REFRACTORY METALS	PRECIOUS METALS
VERY LOW 1 TO 100	[1.5] [1.6] [1.7] [4.M]	[1.5] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.1][1.5][1.7] [3.10] [4.M] [5.1] [5.5] [5.6] [5.7]	[1.5] [1.7] [3.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.5] [1.7] [3.10] [4.M] [5.1]	[1.5] [1.7] [3.7] [3.10] [4.M] [5.5]	[1.6] [1.7] [3.10] [4.M] [5.1] [5.5]	[1.1] [1.7] [3.10] [4.M] [5.5]	[1.1] [1.7] [3.10] [4.M] [5.5]	[1.1] [3.10] [4.M] [5.5]	[1.5] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.1] [1.6] [3.7] [3.10] [4.M] [5.1] [5.5] [5.6] [5.7]	[2.5] [2.7]	[2.5] [2.7]	[2.2] [2.6] [5.7]	[1.1] [5.1] [5.5] [5.6] [5.7]	[1.1] [5.7]	[5.5]
LOW 100 TO 1,000	[1.2] [1.5] [1.6] [1.7] [4.M] [5.3] [5.4]	[1.2] [1.5] [1.7] [4.M] [5.1] [5.3][5.4][5.5]	[1.1][1.2][1.7] [4.M] [5.1] [5.3] [5.4] [5.5][5.6][5.7]	[1.2] [1.7] [3.7] [3.10] [4.M] [5.1] [5.3][5.4][5.5]	[1.2] [1.5] [1.7][1.8][3.5] [3.10][4.M][5.1] [5.3] [5.4]	[1.2][1.5][1.7] [1.8][3.7][3.10] [4.M] [5.3] [5.4] [5.5]	[1.6] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.8] [3.10] [4.M] [5.5]	[1.2][1.5][1.7] [3.10] [4.M] [5.1] [5.3] [5.4] [5.5]	[1.1][1.6][3.7] [3.10][4.M][5.1] [5.3][5.4][5.5] [5.6] [5.7]	[2.5] [2.7]	[2.2] [2.3] [2.6] [2.7]	[2.2] [2.6] [5.7]	[1.1] [5.1] [5.5] [5.6] [5.7]	[5.7]	[5.5]
LOW TO MEDIUM 1,000 TO 10,000	[1.2] [1.3] [1.5] [1.6] [1.7] [3.11] [4.A] [5.3]	[1.2][1.3][1.5] [1.7][3.1][3.3][3.10] [3.11][4.A][5.2][5.3] [5.4][5.5]	[1.2][1.3][1.7] [3.1][3.4][3.11] [4.A][5.2][5.3] [5.4] [5.5]	[1.2][1.3][1.7] [3.1][3.3][3.7] [3.10] [3.11] [4.A][5.2][5.3] [5.4] [5.5]	[1.2][1.3][1.7] [3.1][3.3][3.7] [3.10][3.11][4.A] [5.2][5.3][5.4]	[1.2][1.3][1.7] [1.8][3.1][3.3] [3.7][3.10][3.11] [4.A][5.3][5.4][5.5]	[1.3][1.6] [1.8] [3.1] [3.3][3.4][3.10] [4.A] [5.4]	[1.3] [1.8] [3.2] [3.10] [4.A] [5.5]	[1.3] [1.8] [3.3] [3.10]	[1.3] [1.8] [3.3] [3.10]	[1.2][1.3][1.7] [1.8][3.10][3.11] [4.A][5.2][5.3] [5.4][5.5]	[3.1] [3.7] [3.10] [3.11] [4.A] [5.2] [5.3][5.4][5.5]	[2.5] [2.6] [2.7]	[2.2] [2.3] [2.4]	[2.1] [2.2] [2.3]	[5.2] [5.3] [5.4] [5.5]		[5.5]
MEDIUM TO HIGH 10,000 TO 100,000	[1.2] [1.3] [3.11] [4.A]	[1.3][2.3][3.2][3.3] [3.4] [3.5] [3.11] [3.12] [4.A][5.2][5.5]	[1.3][2.3][3.4][3.5] [3.11][3.12] [4.A] [5.2]	[1.3] [2.3] [3.4] [3.5] [3.11] [3.12] [4.A]	[1.2][1.4][1.9] [3.1][3.3] [3.4][3.5][3.11] [3.12][4.A]	[1.2][1.3][1.4] [1.9][3.1][3.3] [3.4][3.5][3.11] [3.12][4.A][5.5]	[1.3] [1.4] [3.1] [3.3] [3.4] [3.5] [3.12] [4.A]	[1.3] [1.4] [3.3] [3.4] [3.5] [3.12] [4.A]	[1.3] [1.4] [3.3] [3.4] [3.12]	[1.3] [1.4] [3.3] [3.4] [3.5] [3.12] [4.A]	[3.1][3.2][3.5] [3.4] [3.11] [3.12] [4.A] [5.2] [5.5]	[3.1][3.4] [3.11] [3.12] [4.A][5.2][5.5]	[2.1] [2.2] [2.5]	[2.1] [2.2] [2.5]	[2.1] [2.2] [2.5]	[3.11]	[3.12]	[3.5]
HIGH 100,000+	[1.2] [1.3] [3.11] [4.A]	[1.9] [3.1] [3.2] [3.3] [3.4] [3.5] [3.12] [4.A]	[4.A]	[1.9] [3.2] [3.3] [4.A]	[1.2][1.4][1.9] [3.2][3.3][3.4] [3.5][3.7][3.9] [3.11][3.12][4.A]	[1.2][1.3][1.4] [1.9][3.1][3.2] [3.3][3.4][3.5] [3.8][3.12][4.A]	[1.3] [1.4] [3.1][3.3][3.4] [3.8][3.12][4.A]	[1.4] [3.2] [3.3] [3.4] [3.5] [4.A]	[1.4] [3.3] [3.4] [4.A]	[1.4] [3.2] [3.3] [3.4] [4.A]	[3.2] [3.3] [4.A]	[4.A]	[2.1] [2.4] [2.5]	[2.1] [2.3] [2.4] [2.5]		[3.7] [3.11]		[3.5]
ALL QUANTITIES	[1.1]	[1.1] [1.6] [3.8] [3.9]	[1.6] [3.6]	[1.1] [1.6] [3.6][3.8][3.9]	[1.1] [1.6] [3.6] [3.8] [3.9] [5.5]	[1.1] [1.6] [3.6] [3.8] [3.9]	[1.1] [3.6] [3.8] [3.9]	[3.6] [3.8] [3.9]		[3.6]	[1.1] [1.6] [3.6] [3.8] [3.9]	[3.8] [3.9]				[5.5]	[1.6]	[1.6]

KEY TO MANUFACTURING PROCESS PRIMA SELECTION MATRIX:

CASTING PROCESSES
[1.1] SAND CASTING
[1.2] SHELL MOULDING
[1.3] GRAVITY DIE CASTING
[1.4] PRESSURE DIE CASTING
[1.5] CENTRIFUGAL CASTING
[1.6] INVESTMENT CASTING
[1.7] CERAMIC MOULD CASTING
[1.8] PLASTER MOULD CASTING
[1.9] SQUEEZE CASTING

PLASTIC & COMPOSITE PROCESSING
[2.1] INJECTION MOULDING
[2.2] REACTION INJECTION MOULDING
[2.3] COMPRESSION MOULDING
[2.4] TRANSFER MOULDING
[2.5] VACUUM FORMING
[2.6] BLOW MOULDING
[2.7] ROTATIONAL MOULDING
[2.8] CONTACT MOULDING
[2.9] CONTINUOUS EXTRUSION (PLASTICS)

FORMING PROCESSES
[3.1] CLOSED DIE FORGING
[3.2] ROLLING
[3.3] DRAWING
[3.4] COLD FORMING
[3.5] COLD HEADING
[3.6] SWAGING
[3.7] SUPERPLASTIC FORMING
[3.8] SHEET-METAL SHEARING
[3.9] SHEET-METAL FORMING
[3.10] SPINNING
[3.11] POWDER METALLURGY
[3.12] CONTINUOUS EXTRUSION (METALS)

MACHINING PROCESSES
[4.A] AUTOMATIC MACHINING
[4.M] MANUAL MACHINING
(THE ABOVE HEADINGS COVER A BROAD RANGE OF MACHINING PROCESSES AND LEVELS OF CONTROL TECHNOLOGY. FOR MORE DETAIL, THE READER IS REFERRED TO THE INDIVIDUAL PROCESSES.)

NTM PROCESSES
[5.1] ELECTRICAL DISCHARGE MACHINING (EDM)
[5.2] ELECTROCHEMICAL MACHINING (ECM)
[5.3] ELECTRON BEAM MACHINING (EBM)
[5.4] LASER BEAM MACHINING (LBM)
[5.5] CHEMICAL MACHINING (CM)
[5.6] ULTRASONIC MACHINING (USM)
[5.7] ABRASIVE JET MACHINING (AJM)

Figure 47: Prima Matrix table

Upper Shell:

Upper shell is considered to be manufactured of thermoplastic material – ABS Material. As the object is not very complex in terms of shape, it can be easily molded with Plastic

Injection molding which was chosen by above mentioned PRIMA process selection matrix. The price of the chosen ABS material was shown as 74.2 to 76.2 Euro per kg in CES Edu pack with this given information:

Source records
Material = ABS (20% carbon fiber, EMI shielding, conductive)
Primary Process = Polymer casting

Component details
Value of scrap material = 15 % of virgin price
Part mass = 0.077 kg
Part length = 0.23 m
Primary shaping process
Load factor = 20 %
Overhead rate = 50 EUR/hr
Capital write-off time = 2 years
Availability = Custom form
Part complexity = Standard
Additional attributes
Tool life (units) - Primary process = 5818
Capital cost - Primary process = 827.5 EUR
Production rate (units) - Primary process = 5.818 /hr
Material utilization fraction - Primary process = 0.9
Tooling cost per part - Primary process = 0.07483 EUR
Overhead cost per part - Primary process = 8.635 EUR

Model: Cost, Part cost estimator
Date of analysis: 03 April 2022

ABS, Injection MOlding, (0.077kg) - 1000 units

Price

Price	120	-	122	EUR/kg
Notes				
Price generated by part cost estimator and includes processing cost for 0.077 kg component				

With this calculation, Upper shell part cost was estimated to be 9.2 to 9.4 Euro per unit with considering the overhead rate of 50 Euro per hour.

Part cost estimator

Part cost	9.22	-	9.37	EUR
Part mass	0.077			kg
Batch size	1e3			
Material price per part	0.505	-	0.658	EUR
Primary process cost per part	8.71			EUR
Secondary process cost per part	0			EUR
Material price %	6.21			%
Primary process cost %	93.7			%
Secondary process cost %	0			%

Bottom Shell:

Bottom shell is also considered to be manufactured of thermoplastic material – ABS Material. The object consist ribs which are providing the support to the product and also providing space for the electronics. It is also molded with Plastic Injection molding which was chosen by above mentioned PRIMA process selection matrix. The price of the chosen ABS material was shown as 74.2 to 76.2 Euro per kg in CES Edu pack with this given information:

Source records
Material = ABS (20% carbon fiber, EMI shielding, conductive)
Primary Process = Polymer casting

Component details
Value of scrap material = 15 % of virgin price
Part mass = 0.138 kg
Part length = 0.23 m
Primary shaping process
Load factor = 20 %
Overhead rate = 50 EUR/hr
Capital write-off time = 2 years
Availability = Custom form
Part complexity = Standard
Additional attributes
Tool life (units) - Primary process = 5393
Capital cost - Primary process = 892.7 EUR
Production rate (units) - Primary process = 5.393 /hr
Material utilization fraction - Primary process = 0.9
Tooling cost per part - Primary process = 0.0169 EUR
Overhead cost per part - Primary process = 9.319 EUR

Model: Cost, Part cost estimator
Date of analysis: 03 April 2022

ABS, Injection Molding, (0.138kg) - 10000 units

Price

Price	74.2	-	76.2	EUR/kg

Notes
Price generated by part cost estimator and includes processing cost for 0.138 kg component

With this calculation, Upper shell part cost was estimated to be 10.2 to 10.5 Euro per unit with considering the overhead rate of 50 Euro per hour.

Part cost estimator

Part cost	10.2	-	10.5	EUR
Part mass	0.138			kg
Batch size	1e4			
Material price per part	0.906	-	1.18	EUR
Primary process cost per part	9.34			EUR
Secondary process cost per part	0			EUR
Material price %	9.96			%
Primary process cost %	90			%
Secondary process cost %	0			%

Manufacturing cost analysis of upper and bottom shell showed that the price of 20.00 euro in total of the shell. Some components could be obtained by laser cutting which can save some manufacturing cost. These components include Weight plate and support plate. While other component of the product can be found in market and can be bought from other manufacturers which can reduce the cost of the product. This component buying cost can be found in this table shown below:

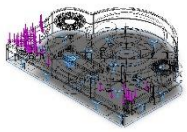
BUY COMPOENENTS	QUANTITY	PRICE PER UNIT
Weight Plate	10,000 Pz	1.00 Euro
Support Plate	10,000 Pz	0.50 Euro
Buttons Cap	30,000 Pz	0.04 Euro
Reset Buttons	10,000 Pz	0.04 Euro
Weight Chip Set (7 Chips)	10,000 Pz	8 Euro
Arduino UNO	10,000 Pz	8.50 Euro
HX711 signal amplifier	10,000 Pz	0.44 Euro
20kg Load Cell	10,000 Pz	3.00 Eurp
Rechargable Battery 9V	10,000 Pz	0.42 Euro
LCD 16x2 Display	10,000 Pz	1.00 Euro
LED Bulb	10,000 Pz	0.01 Euro
8 Watt Speaker	20,000 Pz	0.50 euro

After evaluation all the component cost, the total component cost was achieved 44 euro per unit. With including the assembly cost which was around 4 Euro per unit. It can be found that Total Manufacturing cost of one unit of the Plai Board can be 48 Euros.

6.7 FEM analysis:

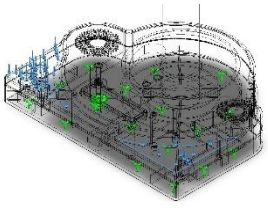
To understand the strength of the product, FEM analysis was conducted on the product structure. The analysis was executed on the Solid works software. Conditions applied to the analysis was understood the stress bearing capacity of the product. The force concentration area was considered near the button and the area which will be closer to children where they can put some force while pressing the buttons. 25N of force considered which can act upon the surface of the product while in the use near the interacting areas like near buttons. Here following data can be found in the simulated result shown below:

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 1 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-0.000305362	50.0014	0.00010678	50.0014
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Force-1		**Entities:** 2 face(s) **Type:** Apply normal force **Value:** 25 N

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.000305362	50.0014	0.00010678	50.0014

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

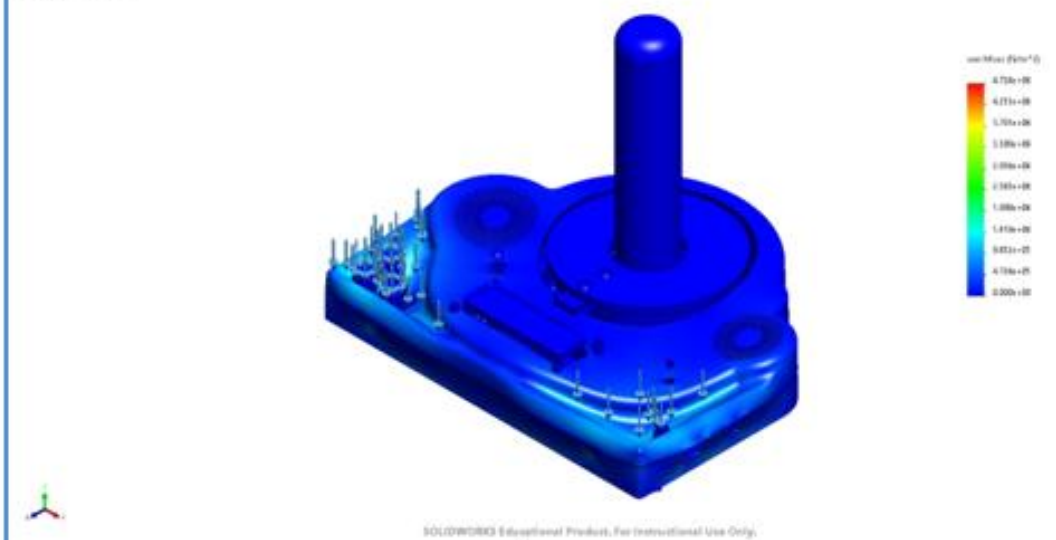
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.000430522	0.00476222	-0.000896277	0.00486491

Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

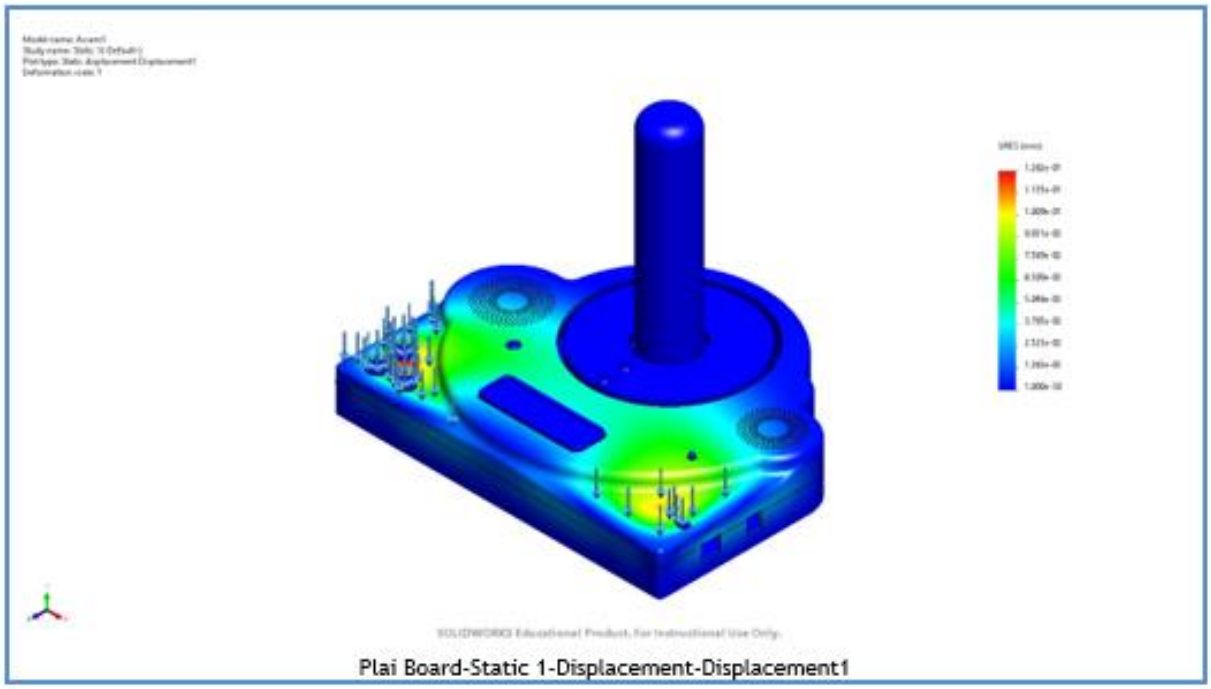
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.000e+00N/m^2 Node: 2380391	4.726e+06N/m^2 Node: 250708



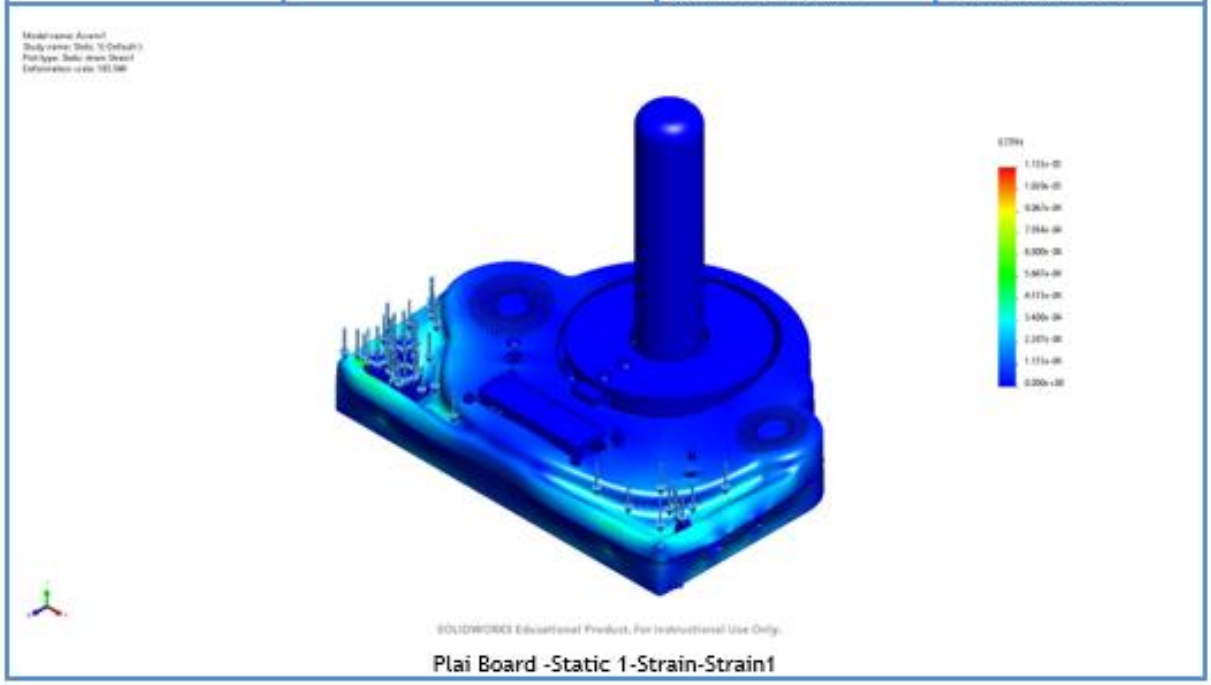
Plai Board-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 250739	1.262e-01mm Node: 3208853



Plai Board-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0.000e+00 Element: 1530869	1.133e-03 Element: 975443



Plai Board -Static 1-Strain-Strain1

In overall analysis, It was found that product can sustain the applied force 25 N in the critical area of the structure.

Product Testing and Validation

After creating the prototype of the PLAi Board, it was tested with children. Testing of the prototype was conducted where children were accompanies with their caretakers. As it provides opportunity for caretaker to interact with children. First the device was introduced to the caretakers then device was introduced to children by caretaker. The game was able to grab attention of the children with its visual feedback and colors. However, audio feedback was difficult to distinguish for the children. As these children have different effect of autism. Thus, it was good to develop their moto skill while for another children change LED color with addition wooden chip was interesting. This was useful for his caretaker to teach color to him. Some children were interested to the game by their own while some child needed to be assisted by their caretakers.

Figure 48: Testing 01

In overall the testing was helpful to observe the children behavior toward the game. As well caretaker provided their opinion over the usefulness of the games and suggested their improvement which can be added to make the game more efficient from present stage. While using the game, caretakers were interacting with children and assisting them over the choosing stage of color chips. This was needed in the guiding stage of the game where child was getting familiar with the game.

Figure 49: Testing 02

After the testing of the PLAi Board, It has been validated through using the System Usability Scale (SUS). It is a tool to evaluate wide variety of products and services, including hardware, software, mobile devices, websites, and application. It is an industry standard for evaluating before mentioned products. It can be measures the usability by using the set of questionnaires with five responses ranging from strongly agree to strongly disagree. It is able to assess the user satisfaction with this questionnaire.

Figure 50: Testing Phase:- Caretaker feedback

The caretakers assisting the children with autism were asked below mentioned questions for SUS validation to score the usability from answer ranging from strongly agree to strongly disagree.

1. Would you like to use this device frequently for the child?
2. Do you find this system unnecessarily complex?
3. Was this device easy to use?
4. Do you think that you need the support of a technical person to be able to use this system?
5. Do you find various function in this system well integrated?
6. Did you find too much inconsistency in this product?
7. According to you, would most people learn to use this product very quickly?
8. Did you find the product cumbersome to use?
9. Did you felt confident while using the product?
10. Do you think that you need to learn a lot of things before you could get going with this system?

After performing the testing, I observed children response toward the product as well the product performance toward the expected goal. Additionally, the responses I have received from caretakers about the SUS questionnaires are:

1. *Would you like to use this product frequently?*

   Strongly agree, it is good product to teach about color and shapes. However, it needs some update according to child. In overall, I found it interesting for children and I would like to use it frequently.

2. *Do you find this device unnecessarily complex?*

   Disagree, however it is needed to understand the steps for the game in first usage then it is easy to follow.

3. *Was this device easy to use?*

   Agree, it is easy to follow as there is a display with text and LED feedforward. However, before it needs to be calibrated and game level need to be selected which should be done by either parents or caretaker.

4. *Do you think that you need the support of a technical person to be able to use this system?*

Strongly Disagree, there is no need of technical person to assist the use of the product.

5. *Do you find various function in this system well integrated?*

   Agree, I find the functions of the device well integrated. The guiding game helps to understand the color. Also, free play game is quite interesting. However, it is needed to add more recognizable audio files in the system.

6. *Did you find too much inconsistency in this product?*

   Disagree, I find the device consistent. However, as I have mentioned before that there is some update is needed in audio feedback. Those two levels can be more connected. There is extra step of calibration which, if possible, can be reduced.

7. *According to you, would most people learn to use this product very quickly?*

   Agree, As I have mentioned for first time user need to give attention because it has long steps, but all steps are guided on screen display. Therefore, firstly it needed to be understood by parent or caretaker as it required scale calibration and game level selection then it can be introduced to children.

8. *Did you find the product cumbersome to use?*

   Disagree, as it was seen that product only take time in initial setup. Once the game is setup then it can be quick to use.

9. *Did you felt confident while using the product?*

   Agree, it is a good concept. It gives good opportunity for children to play and learn about something new. As it is in prototype condition, but I feel confident to use it now and further when it can be available as fully developed product.

10. *Do you think that you need to learn a lot of things before you could get going with this system?*

Strongly Disagree, product have clear instruction which can be easily followed in order to operate the game. LED written instructions help to follow all the steps needed to start the game/ Therefore, I don't think there is any need to learn anything new to get going with this product.

After asking the questions from the caretakers and seeing the children response, I used SUS Scoring strategy to understand the usability of the product. With following the standard scoring calculation, I created the score as shown in below chart:

USER	QUESTION 01	QUESTION 02	QUESTION 03	QUESTION 04	QUESTION 05	QUESTION 06	QUESTION 07	QUESTION 08	QUESTION 09	QUESTION 10	SUS SCORE
1	5	2	4	1	4	2	4	2	4	1	82.5
2	4	3	4	1	4	3	4	2	4	1	75

Table 1: SUS Score

With this validation and usability rating, I received the rating for the product around 75 and 82.5 which is considered to be good. The rating guideline on the interpretation of SUS score is like:

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Table 2: Grading structure for SUS

Results

Plai board was developed as an interactive musical toy. It was found that it is important for autistic children to learn some basic development skills in their early age. With the development of the PLAi Board, the goal was to satisfy this requirement. To understand the result of project, Testing was conducted with autistic children and their caretakers. During the test, it was found that every children have different personality and have different behavior toward some objects. Device was able to grab the attention of some children while for other, it was needed to be introduced by their caretakers. For an example, one child who was having difficulties with interacting with other children was interested in the product and he tried the product with his caretakers. Testing of the product was very important to understand its effect on its target. It was found that the product was able to make children think about color which was helpful to make them practice their cognitive skills. While for the children who lack in hand eye motor skills, it was interesting to see them focusing their hand motion to putting color chip on the product to achieve the game goal. This LED feedback and specially caretakes appraising was encouraging them to add color chip and get new color on LED.

However, there is some needed improvement which was observed during the test. According to the caretaker, Audio feedback was interesting to use. But It was difficult to distinguish for the children. So, it was suggested to add other distinguishable sound to the chip feedback in the device.

Conclusion

The goal of the project was to develop the interactive product which help autistic children to learn early development skills. In order to achieve this goal, the process of development of this product involved intense research, several designing exercise, prototype development including software and hardware implementation and testing. Interactive feature in the product promises more gamified way of learning. Thus, PLAi board was able to add learning with gamification, reducing the direct pressure to finish some activity. It was proven that for some children who have difficulty to interact and want to play alone was more comfortable while playing with the Plai board instead of getting worried about surrounding.

During the testing, it was proven that Plai board is able to provide some activities which help early development skills in autistic children whether it is cognition thinking or hand eye motor skill coordination. However, there needed improvement which were observed during the testing and some suggestions were given by caretakers in order to update the product in future.

Future work

PLAi Board aimed to provide basic exercises which can help children to learn basic development skills with minimal interaction. Although product was able to achieve this goal. However, there are some improvements which was suggested by caretaker and observed during the testing. Additionally, there can be future development of the product which can help to improve the function of the product.

During the testing process, it was observed that product need to have more distinctive musical feedback which can be easily observable to them and more customized music which can be customized according to the context of learning. It can bring up the role of application. An application which can be connected to the product which addition of internet connectivity to customize the added music notes.

Presently, the product can recognize and work with only 7 chips but in future it can have possibility higher quantity of chips with more precision. This can add the extra possibility for children to keep continuing the game after seven chips.

PLAi board can be implemented to Artificial bot Intelligence which can provide live feedback to the children while they engage themselves with the game. It will be able to interact the children and guide them and teach them through artificial voice guidance.

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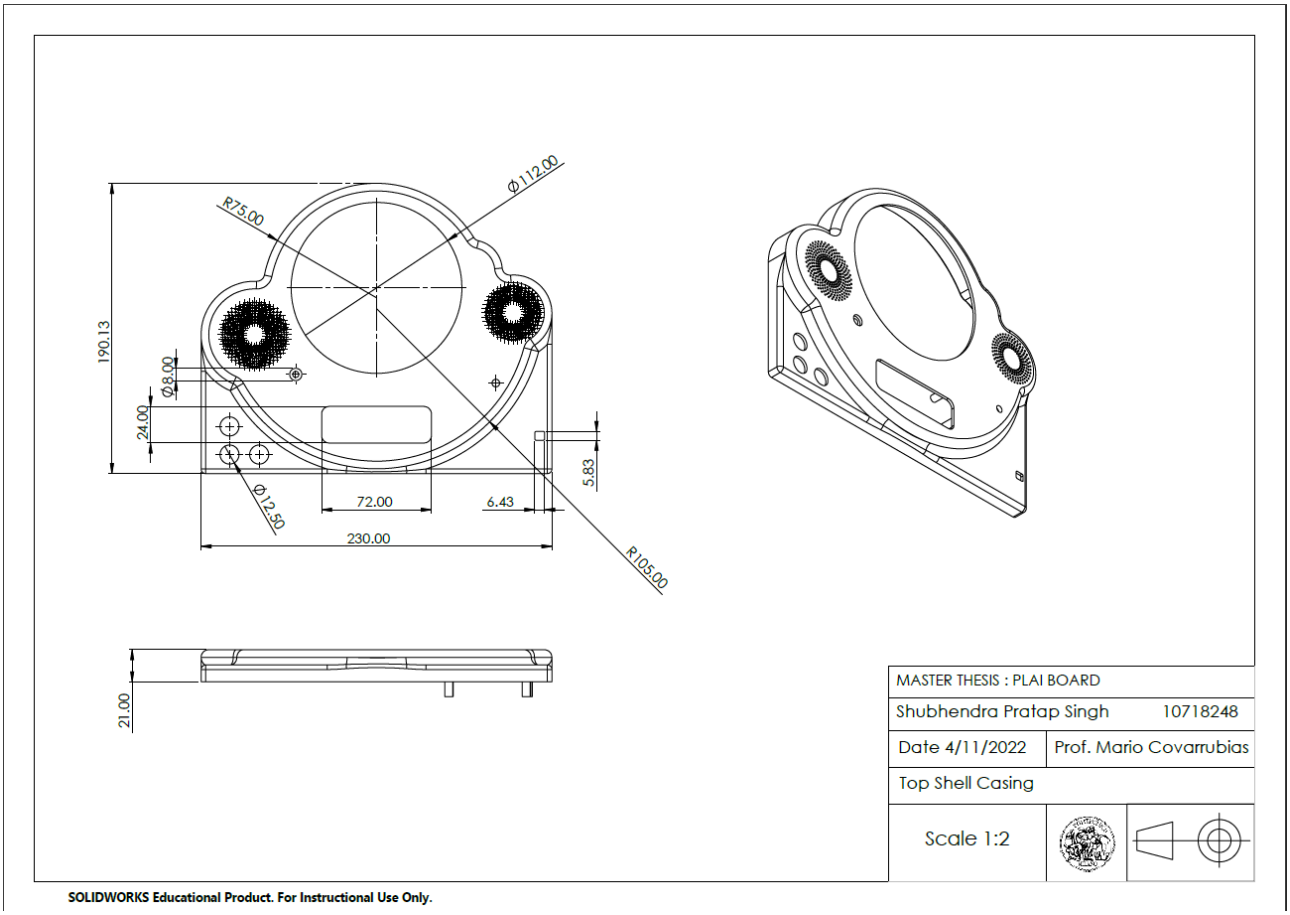
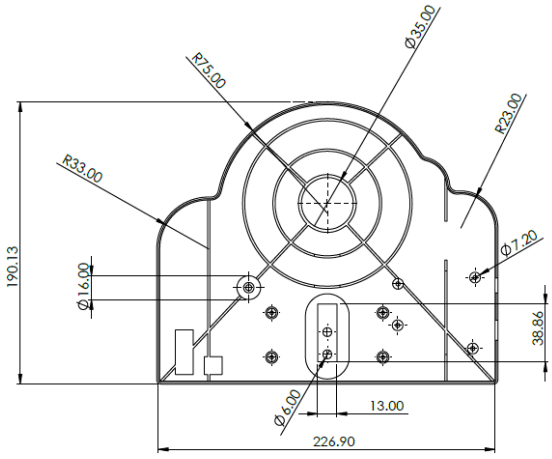
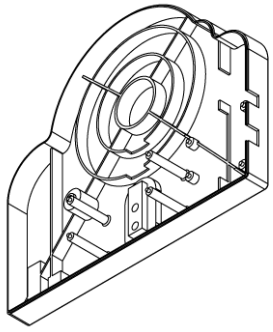
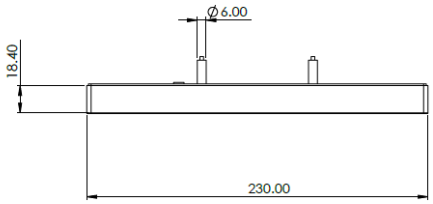
Appendix 01

Appendix 01 includes the technical drawing of the upper and bottom shell of the device structure. It consists of two manufacturing part which is Upper shell and bottom shell.



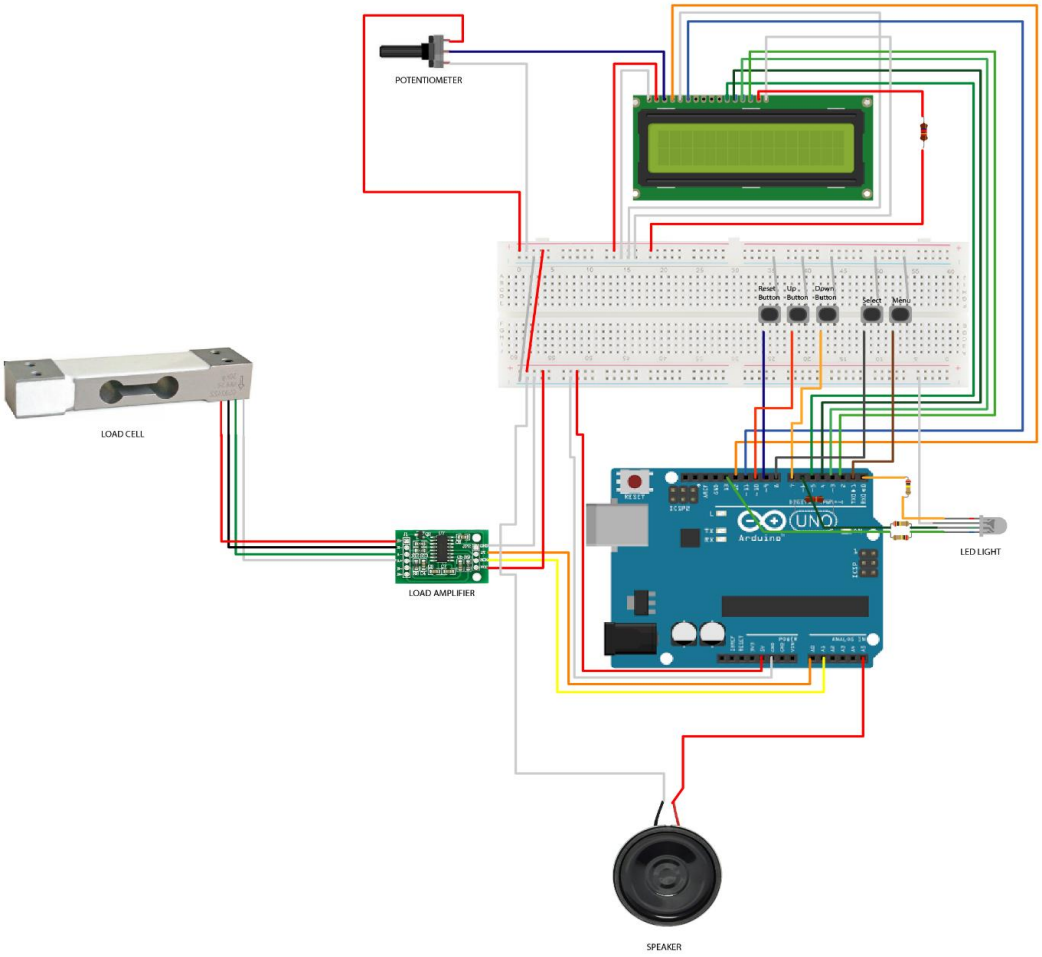






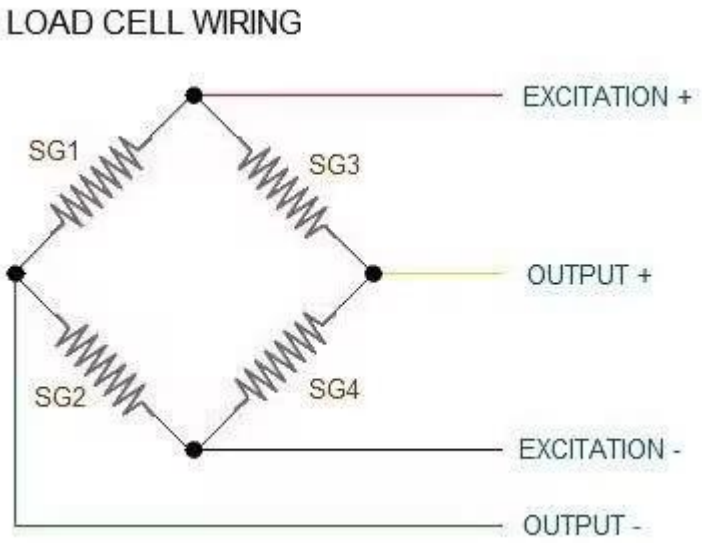
MASTER THESIS: PLAI BOARD	
SHUBHENDRA PRATAP SINGH 10718248	
Date 4/11/2022	Prof.Mario Covarrubias
Bottom Shell	
Scale 1:2	

Appendix 02



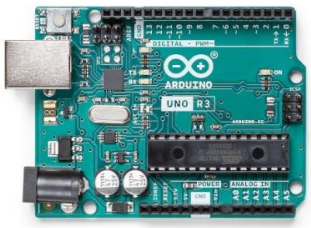
This diagram shows all connection used in the whole circuit of the device. White wire denoting all ground wires and Red wires representing all the voltage wiring.

Appendix 03



Load cell works on the working principle of Wheat stone bridge. A Wheatstone bridge is a network of four resistive legs. One or more of these legs can be active sensing elements. Any physical phenomenon such as change in strain applied to the loadcell; it changes the resistance in these four legs. This small variation of resistance on legs can be measured by the load cell amplifier (HX711).

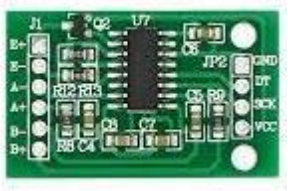
Appendix 04



Features

- **ATMega328P** Processor
  - **Memory**
    - AVR CPU at up to 16 MHz
    - 32KB Flash
    - 2KB SRAM
    - 1KB EEPROM
  - **Security**
    - Power On Reset (POR)
    - Brown Out Detection (BOD)
  - **Peripherals**
    - 2x 8-bit Timer/Counter with a dedicated period register and compare channels
    - 1x 16-bit Timer/Counter with a dedicated period register, input capture and compare channels
    - 1x USART with fractional baud rate generator and start-of-frame detection
    - 1x controller/peripheral Serial Peripheral Interface (SPI)
    - 1x Dual mode controller/peripheral I2C
    - 1x Analog Comparator (AC) with a scalable reference input
    - Watchdog Timer with separate on-chip oscillator
    - Six PWM channels
    - Interrupt and wake-up on pin change
  - **ATMega16U2 Processor**
    - 8-bit AVR® RISC-based microcontroller
  - **Memory**
    - 16 KB ISP Flash
    - 512B EEPROM
    - 512B SRAM
    - debugWIRE interface for on-chip debugging and programming
  - **Power**
    - 2.7-5.5 volts

Appendix 05



海芯科技 AVIA Semiconductor

HX711

24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales

DESCRIPTION

Based on Avia Semiconductor's patented technology, HX711 is a precision 24-bit analog-to-digital converter (ADC) designed for weigh scales and industrial control applications to interface directly with a bridge sensor.

The input multiplexer selects either Channel A or B differential input to the low-noise programmable gain amplifier (PGA). Channel A can be programmed with a gain of 128 or 64, corresponding to a full-scale differential input voltage of ±20mV or ±40mV respectively, when a 5V supply is connected to AVDD analog power supply pin. Channel B has a fixed gain of 32. On-chip power supply regulator eliminates the need for an external supply regulator to provide analog power for the ADC and the sensor. Clock input is flexible. It can be from an external clock source, a crystal, or the on-chip oscillator that does not require any external component. On-chip power-on-reset circuitry simplifies digital interface initialization.

There is no programming needed for the internal registers. All controls to the HX711 are through the pins.

FEATURES

- **Two selectable differential input channels**
- **On-chip active low noise PGA with selectable gain of 32, 64 and 128**
- **On-chip power supply regulator for load-cell and ADC analog power supply**
- **On-chip oscillator requiring no external component with optional external crystal**
- **On-chip power-on-reset**
- **Simple digital control and serial interface: pin-driven controls, no programming needed**
- **Selectable 10SPS or 80SPS output data rate**
- **Simultaneous 50 and 60Hz supply rejection**
- **Current consumption including on-chip analog power supply regulator: normal operation < 1.5mA, power down < 1uA**
- **Operation supply voltage range: 2.6 ~ 5.5V**
- **Operation temperature range: -40 ~ +85℃**
- **16 pin SOP-16 package**

APPLICATIONS

- **Weigh Scales**
- **Industrial Process Control**

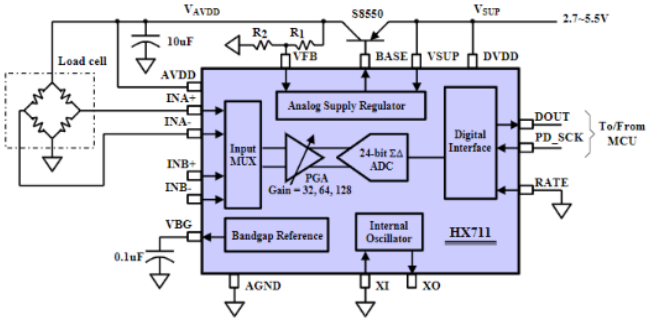


Fig. 1 Typical weigh scale application block diagram