CRITERION A: Description of the problem

A group of children at the village international education centre, as a result of their developmental disorders, need high levels of sensory stimuli to calm down and to improve their sensory skills. Without sensory exposure when young, these children will continue to experience sensory sensitivity when older, leading to negative emotional responses to certain sensory experiences, and inability to concentrate - causing difficulty in completing simple everyday tasks.

However, the children simultaneously have very strong preferences as to which sensory stimuli they enjoy. Once a child finds a sensory object they like, it is difficult to encourage them to interact with other objects / new experiences. Their short attention span also makes it difficult to keep them engaged in a sensory experience. Finally, they are prone to experiencing distress when exposed to overwhelming sensory stimuli. In the new Sensory Room to be built at the centre, these problems need to be addressed. Such issues and Sensory Rooms exist not only in the centre, but also throughout Southeast Asia and the rest of the world. Therefore, a safe way to introduce children with sensory sensitivities to, and to keep them engaged in, new sensory stimuli needs to be developed.   (198 words)

Photos of the problem

Staff explaining the children's sensory needs to me

F1a

"The children will need to be exposed to more sensory stimuli."

"The children can be easily distracted, distressed or sensually overwhelmed"

Height 237cm

Floor 441 x 397cm

F1b

Area that will be made into Sensory room

Where product will be used and stored

F1c

Toy meant to allow children to explore tactile/visual stimulation

Many children scared by bright colours and spikes

Egg-shaped shakers: each colour generates different sound (tactile, aural, visual)

F1e

F1d

Different textures for children to play with (beans, rice, stones)

"Children mostly play with the beans and rice" - Staff

"N only likes the sound of the orange egg" - Staff

"It's difficult to get N to explore other sounds" - Staff

Function and performance

F2a

F2b

> Sensory Rooms can help those who have learning difficulties, developmental disabilities or sensory impairments learn to interact with the world around them, but in a safe environment that builds up their confidence and their ability. The user gets an unrestrained non-threatening space where they can explore at their own leisure. This freedom lets their teacher, therapist or carer see what calms them, rouses them and what they like or don't.
>
> • Sensory Stimulation – by encouraging the user to engage and explore the environment then it can have positive effects on their ability to react and interact with the larger world around them

https://www.experia-innovations.co.uk/blog/the-benefits-of-a-sensory-room/

Purposes of sensory products in sensory rooms

The children find repetition calming (from observation)

"The children can be distracted or sensually overwhelmed easily" - Staff

"The children need to improve their sensory skills" - Staff
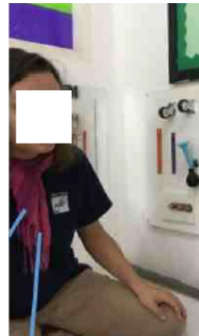
Safety

F3a

Developmental disorders or syndromes

Children 6-9 years old

Inclined to place objects in mouth, bite, scratch, hit, throw
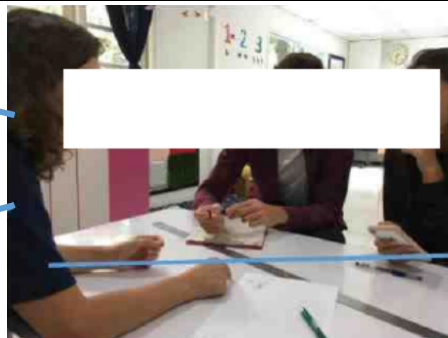
F3b

"There are children with epilepsy around" - Staff

"Children may not always supervised in the room" - Staff

F3c

Limited fine motor skills, prone to dropping objects

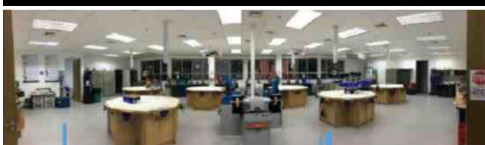# Aesthetics

"Bright, strong colours are likely to overwhelm the kids"

"Pastel colours are safer to use with the children"

F3a

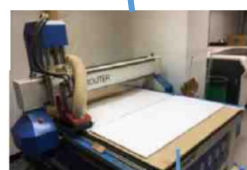"Different children have different sensory preferences"

Manufacture

F3a

One-off/batch production

Workshop

Craft (one-off) production

F3a

3D printers

F5c   CNC Router

F5d Laser Cutter

Size and Environment

F6a
F6c

96 cm

198 cm

F6b
90 cm

237 cm

397 cm

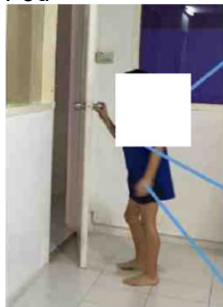441 cm
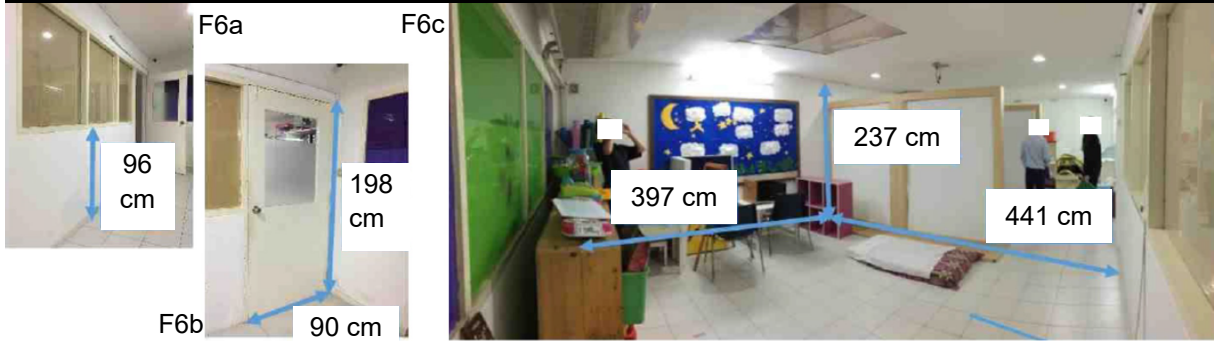
F6d

Children ~90-120cm in height

Inclined to place objects in mouth

Small hands

Air-conditioned

F6e

Product will remain in the room with other products
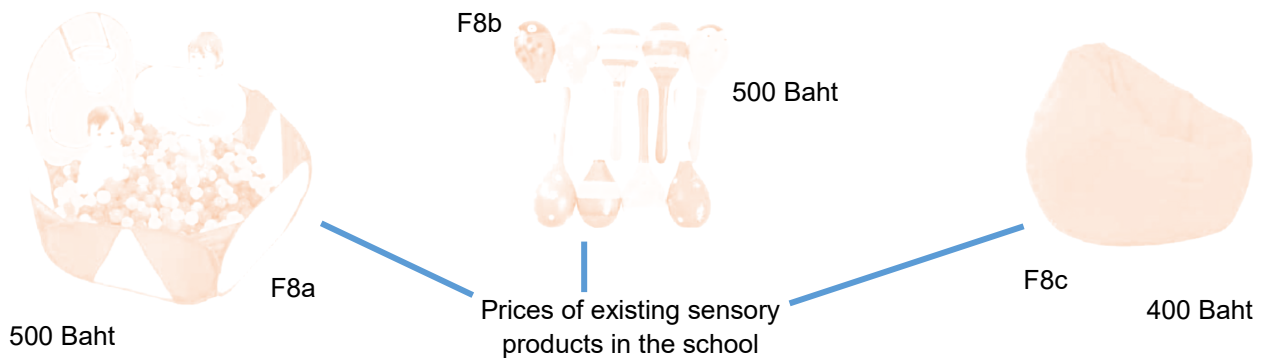
Room will have lighting

Materials

F7a

"The children have lots of strength and energy" - Staff

Children drool and need to be kept in hygienic environment

Children have limited motor skills and control, often drop objects

Cost

F8b

500 Baht

F8a

500 Baht

Prices of existing sensory products in the school

F8c

400 Baht

User

Mostly suffer from autism (or other developmental disorders

6-9 years old

~90-120cm in height

Lack of coordination

Find comfort in repetition, interest in new objects

"A stable, structured environment rich in stimuli could help children with autism, by providing a safe haven from an overload of sensory and emotional stimuli. In contrast, an environment with many unpredictable, changing stimuli could make their symptoms worse, raising anxiety and fear and making these children retract into a bubble," says Kamila Markram.

https://www.sciencedaily.com/releases/2015/06/150602164024.htm

Limited reach

Like pastel colours. Can be distressed by bright, strong colours

"They need to learn cause and effect, understand systems" - Staff

"Unable to communicate their thoughts verbally" - Staff

Short attention span (varies from child to child)

- Florescent lights which flicker and/or buzz
- Smells from cleaning supplies, new carpets, perfumes, certain foods, and cologne
- Fluttering curtains, posters, and other wall hangings
- Persistent sounds such as landscapers mowing lawns or blowing leaves, babies crying or even cooing, dogs barking outside, ticking clocks, dripping water, traffic noises, etc.
- Foods and materials with specific textures (these vary from person to person, but slippery, goopy foods and materials such as glue, gels, etc. are often problematic)

Possible sensory overloading for the children

https://www.verywellhealth.com/autism-and-sensory-overload-259892

Design Brief

The product needs to introduce new sensory stimulation to the children, keeping them engaged without distressing them. The children should be able to explore, understand and learn how to use the product independently and safely. To encourage them to do so, the product should be fun and interesting for them to use.

The product should withstand repeated use as it will be used at least once daily.

The final outcome will be a fully-functioning prototype.

The children have developmental disorders (especially autism) and are between 6-9 years old.

This project is constrained by budgets, limited transportation capacity and the children's inability to communicate their thoughts effectively (feedback).

If the child is deemed (by staff) to be engaged with the product for a desirable period of time, being exposed to new stimuli, the product will be considered successful.

This project is feasible as there is a wide range of manufacturing techniques available and the school is very accessible. However, there are risks as certain iterations could be distressing to certain children (higher on the autism spectrum) and could leave a lasting negative effect on them.

(184 words)

Design Specifications

Specifications		Justification
Function	Must introduce sensory stimuli to the children, holding their attention while without distressing them	F2a: staff at the school explain the children need to improve their sensory skills (through being exposed to new sensory stimuli). F2b: the benefits of this for the children. F1a: staff explain the children will receive limited benefits from the product if they are easily distracted from it or feel distressed by it.
	Should show user some cause and effect	F9c: staff mentioned the children need to learn cause and effect.
Performance	Must be able to be stored	F2a: staff explain the children are very easily sensually overwhelmed. If children walk through the Sensory Room and the product is exposed / active, they could be distressed by it. It should be able to be stored, covered, hidden or switched off when not in use.
	Must be simple enough for the children (and staff) to operate	F9c: the children will likely be unable to ask questions about / give verbal feedback on the product. Thus, it has to be understandable enough for them to use and explore independently.
	Must be able to perform the task many times	F2a: staff explain the children find repetition calming -they are likely to interact with the product in the same way repeatedly. The product should also be engaging (F9a).
Safety	No sharp corners / edges	F3a: the children's age range to be very young. Sharp corners / edges would be very dangerous for them to be around - they could cut or scratch themselves on them. F3a: also notes the children could throw the product or use it to hit others/ themselves, and F3c explains they drop objects easily, so sharp / pointed edges would pose safety hazards.
	Must not have detachable parts small enough to be placed in mouth	F3a: the children have a tendency to bite / put things in their mouth. Small parts would be a serious choking hazard for the children, especially when not supervised (F3b).
	Must not give off flashing lights / loud sounds	F3b: staff explain there are children with epilepsy around. Flashing lights and loud sounds could trigger a fit.
Aesthetics	Must not have bright, strong colours	The children can be distressed by such colours (F4a). Pastel colours are ideal (F9c).
	Provide a range of sensory stimuli for the children to experience	F4b: staff explain "different children have different sensory preferences". Providing a range of sensory stimuli allows the product to appeal to and thus to help as many children as possible.

416 words

Design Specifications

Specifications		Justification
Manufacture (and scale of production)	One-off / batch production	F5a-F5d: a range of manufacturing possibilities that enable the product to be one-off or batch produced. However, the product should be more suited to batch production as it is meant to appeal to a range of sensory needs rather than to the needs of one specific child.
Size	Must be able to be within user's reach	F6d: the children are approximately 90-120cm in height and have around 30-40cm arm length. For them to be able to effectively interact with the product, the product should be manipulatable within their reach. If mounted on the wall, the product will also have to be mounted at a height lower than 96cm, due
	Must be able to be manipulated by the children	F6d: the children can be seen to have small hands. Due to their age, they also have limited strength. They also lack body coordination. Thus, the product cannot be too big, too heavy or too complicated for the children to manipulate.
	Must not be able to be placed completely in the mouth	F6d: the child's tendency to place things in his mouth. If the object is too small, children could put it in their mouths and face the risk of choking.
Environment	Will be kept indoors	The product will be kept in the Sensory Room (F6e).
Materials	Should be waterproof/ easy to clean	The product has to be easy to clean or waterproof so it can be kept hygienic for the children to use. If not waterproof, children's drool could be absorbed by the product, making it unhygienic for use. (F7a)
	Must be tough	F7a: described to be very strong and particularly energetic. At the same time, they are limited in their ability to control this energy (F9a) - for example, they are likely to drop / throw objects. Thus, the product must be tough and not brittle / easily broken.
Cost	Must not cost more than 500 baht	Other existing sensory products in the school cost up to 500 baht (F8a-F8c).
User	Must be suitable for users 6-9 years old	F9a: a student within this age range who will use the Sensory Room. The staff informed us of this age range. The product should be suited to be engaging and attractive for children this age.
	Must not have unpredictable, changing stimuli.	F9b: such features could be detrimental to the children's condition. F9d provides examples of such features (such as flickering lights).
	No "goopy" / sticky textures or persistent sounds	F9d: these upset some children.

419 words

Criterion B: Initial concept sketches

Different modules can require different manipulation and strength

Simple form

Grooves/bumps provide tactile and aural stimulation

Sharp corners and edges

Fixed frame limits range of sensory stimuli available / adjustable

Spinning capsules with bits give visuals and aural stimulation

Grooves/ may become loose with repetitive use

May be difficult to use if joints not rigid enough

Easy to fold up and store away

Requires a lot of space

Floor textures > higher levels of tactile stimulation (can lay/ crawl)

If child dislikes one texture, they cannot access other stimuli

Range of stimuli

Materials can easily be put in mouth

Materials could easily fall / be removed; thus hard to clean

Mostly tactile simulation

Low fear factor as all stimuli are visible

Lack of opportunity to improve sensory adventureness/confidence

System will be designed so only staff can open box

Cause and effect (child 'rewarded' with picture for exploring stimuli)

Sharp corners and edges

Tactile stimulation

Enclosing stimulus in box removes risk of visual overload / distress

Some may be afraid to touch something they cannot see

Limited visual and aural stimulation

Adjustability, as the stimuli (and reward) can be easily changed

Tactile stimulation

Limited adjustability

Limited stimulation: tactile only

Cause and effect shown

Aural stimulation

Limited manipulation

Stimuli cannot be easily changed once product is sown together

May become boring over time

Range of tactile and visual stimuli can be incorporated

Difficult and time-consuming to manufacture given current tools

Children with developmental disorders find soft blankets comforting
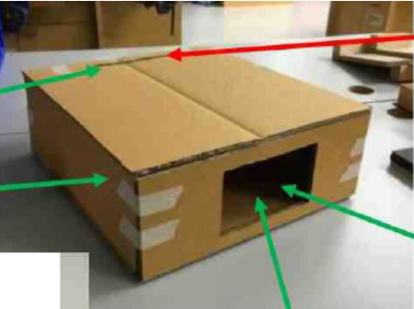
Autism and developmental disorders are most often accompanied by sensory and affective problems. The deep pressure exerted by the closely spaced sensory weighted blanket allows children with these disorders to feel comfortable. How? The body experiencing decisive oppression becomes more static, organized and calmer. In such a state, it is easier to focus, relax, calm at bedtime or relieve stress.

https://senso-rex.com/how-can-weighted-blanket-help-a-child-with-autism/

Improvement to current texture wall in centre (adjustable/ interchangeable)

Can be easily mounted on wall for security

Interchangeable visual and tactile stimulus to accommodate range of needs

Some may not want to touch something they cannot see

May be complicated/ overwhelming (multiple sensory stimuli and movements required)

Sharp corners, edges

Only tactile simulation

Visual stimulus can correlate to tactile stimulus (improves sensual understanding)

Insides may be difficult to clean, since enclosed

Stimuli may be too specific in nature

Range of stimuli available

Could be repetitive and consequently boring

Limited manipulation

Easy to store and clean

Limited adjustability of stimuli if it is simply a fixed board

Difficult to integrate more than one sense into each 'tube'

Using track improves proprioceptive sensory systems (fine motor skills)

All stimuli have to be contained within tube shape

May involve too many stimuli at once > sensory overload

Simple concept to understand

Range of aural stimuli

Easily understandable form and use

Portable and easily stored

Range of stimuli can be included and interchanged

If user dislikes one stimuli, could avoid entire product

Simple to operate allows quick and easy modifications to stimuli

May be boring depending on modules available

Merely conceptual at this stage, no ideas for modules yet

Limited cause and effect shown

Feedback will be limited

Center already has something similar (without interchangeability): may be boring

Adjustability allows for accommodation of range of needs and senses

Initial concept modelling

Cause and effect shown

Easily stored

Position of reward is too predictable: less engaging over time

Less interaction with stimuli while finding object over time

Reaching into darkness and finding reward is exciting, once demonstrated

Almost forces children to feel texture to get reward

Children were very interested

Child was interested for a continuous 15 minutes

Requires initial demonstration by staff of how to use

Child's first instinct is to look into hole—defeats purpose

"Gets them to use their brain to find the object"

"Interchangeable textures and rewards keep it interesting"

Safe: no choking hazards, loud sounds or bright lights

If they see the texture, may avoid whole product forever
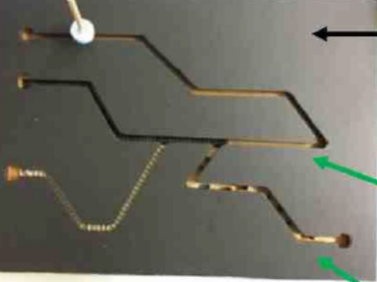
Once children see lid opened, want it to stay open

Defeats purpose of keeping texture unseen

Openable feature unnecessary: "minimal danger hazards without it" - Staff

High level of manipulation possible

Idea 1

"Being easily mounted and taken off walls would benefit" - Staff

"Having four tracks is just right" - Staff

Easily stored / covered

"Limited tactile stimulation if using a dowel— Director

"The track is randomly shaped" - Director

"Opaque surface creates element of surprise" - Director

"Letter shapes would be better if training motor skills" - Director

Children like the sounds, especially corrugated cardboard (auditory stimulation)

Relatively difficult for children younger than 10 years

Safe: no choking hazards, loud sounds or bright lights

Requires detailed instruction to understand (supervision required)

Child did not stay interested for more than 2 minutes

Detachable foam nob helps children with weaker grip

Stopper makes it difficult to trace track

But stopper keeps dowel in contact with track

Idea 2

Initial concept modelling

Smooth plastic gives little grip, little tactile stimulation

Hazard: hands could get trapped

Tactile and auditory stimulation from vertical capsule movement

Resistance given by track good: children need to burn energy

Good for hyper/angry children

Size allows it to be easily stored

Spinning capsule gives very good visual, auditory, tactile stimulation

Calming effect

Individual module > some children more willing to interact with dislikes

"Having interchangeable modules will allow for choice-making—educationally beneficial" - Director

Some children have lots of strength with little control

Tendency to exert huge force, without learning control through product

Permanently-attached modules (initial sketch): child may only like + use one

Large capsule size is good: helps children with less strength

Vertical capsule movement

Spinning capsule

Very high level of manipulation possible

Idea 3

Scale model, 8 times smaller

4 different textures on floor

Children can feel textures with whole body

May require too much space, given size of sensory room

Difficult to store

Appropriate for nap or relaxing time

"4 textures is too many. 2 is better" - Staff

3 sides > enclosed space: only one child at once

Spinning capsules give very good visual, auditory and tactile stimulation

Safe: no choking hazards, loud sounds or bright lights

Children incentivised to crawl on textures they dislike towards capsules

Different shapes and fillings can be used

Idea 4

Idea 5

Natural tendency to look into hole, defeating purpose

Appropriate for nap or relaxing time

Difficult to store

Can help children link the visual and tactile stimuli, but:

"Linking visuals and texture his way is too complex" - Staff

Too complicated for the young children to understand

Children were not very interested in it

No cause and effect

Limited manipulation possible: only touching a static object

Awkward arm and hand positioning required: may be uncomfortable

Evaluation against Design Specification

Specification point (maximum 5 points per point)	Idea 1	Idea 2	Idea 3	Idea 4	Idea 5
Must provide sensory stimuli to children, holding attention without distress	5	3	4	3 (scale model was limited in testability for this specification)	2
Should show user some cause and effect	5	3	5	3	2
Must be able to be stored	5	5	5	2	3
Must be simple enough for the children (and staff) to operate	4	3	4	5	3
Must be able to perform the task many times	5	5	3	5	4
No sharp corners / edges	3	3	5	3	5
Must not have detachable parts small enough to be placed in mouth	5	5	5	5	5
Must not give off flashing lights / loud sounds	5	5	5	5	5
Must not have bright, strong colours	5	5	5	5	5
Provide a range of sensory stimuli for children to experience	3	3	5	5	3
Must be able to be within user's reach	5	5	5	5	3
Must be able to be manipulated by the children	4	3	5	3	2
Must not be able to be placed completely in the mouth	5	5	5	5	5
Will be kept indoors	5	5	5	5	5
Must be suitable for users 6-9 years old	5	3	5	5	3
Must not have unpredictable, changing stimuli.	4	4	4	4	4
No "goopy" / sticky textures or persistent sounds	5	5	5	5	5
Totals (maximum 85 points)	78	70	80	73	64

Feasibility of the ideas

Category (maximum 5 points per category)	Idea 1	Idea 2	Idea 3	Idea 4	Idea 5
Fulfilment of brief (based on 'Evaluation against Design Specifications')	4	4	5	4	2
Client feedback	5	3	5	3	2
Expert appraisal	4	3	5	3	2
Possibility of manufacture	5	5	5	3	3
Cost (how ideal)	4	4	4	3	3
Availability of materials	5	5	5	4	5
Environmental friendliness	4	4	3	3	4
Originality	5	4	5	5	5
Totals (maximum 40 points)	36	32	37	28	26

I will develop Idea 3. Firstly, it received the highest points for the design specifications and feasibility study, implying that it is the most feasible and applicable.

The children were most engaged with Ideas 1 and 3, using them for long periods of time. However, Idea 3 was chosen over Idea 1 as it provided a much larger variety and intensity of sensory stimulation: Idea 1 provided only tactile with some visual stimulation, while Idea 3 exposed children to strong visual, tactile and auditory stimulation, additionally training their motor skills and control of strength through the capsule movements.

Ideas 2 and 5 similarly provided a limited range of stimuli. There were also simply more ways for the children to manipulate Idea 3, which is engaging and enriching for them. These observations were supported by staff feedback and expert appraisal.

Idea 3 is also a manageable size, making it more feasible to produce than Idea 4, which would require much space and materials. Staff and experts suggested there were many ways to refine Idea 1, meaning potential for idea development.

I will develop Idea 3, focusing on improving its adjustability to suit different needs and preferences. This was inspired by staff feedback that some children would be better challenged with several modules presented to them, while others could be distressed and would be better suited to a single module.

Expert appraisal also suggested certain children would prefer capsules and capsule tracks requiring more advanced skill sets. Training horizontal hand motion would also benefit. Hence, developed models could incorporate attaching mechanisms allowing modules to be linked, rotated or detached when needed, interchangeable capsules, different track systems, and other refinements to align the product more with the brief.

(285 words)

Development of Chosen concept
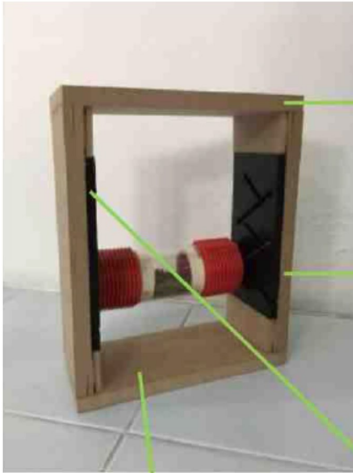
Variety of frames with different tracks will be available

To expose children to wider range of stimuli

Individual modules to be interlocked in different configurations (improves adjustability)

Capsule can be removed and interchanged via capsule-changing mechanism

MDF was suitably hard for use

Capsules with varied designs
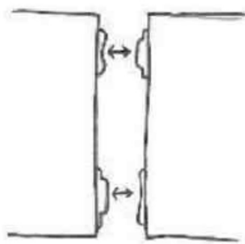
PLA used for capsules was suitably durable

Higher fidelity, 3D printed models to test developed ideas

Module-interlocking mechanism

Concepts

Allowing modules to interlock could improve adjustability of product

Developed different mechanisms to enable interlocking possibility

Press studs

Magnets
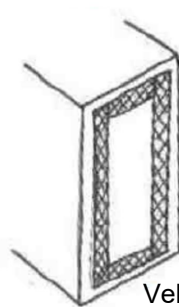
Velcro
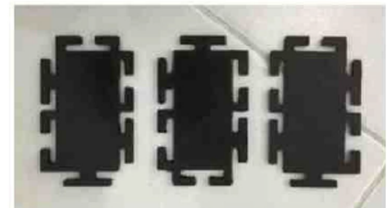
Interlocking mechanism (allows configurations combining horizontal and vertical orientation)

Feedback

"We'll only give a child one module at a time"

"More than one module attached together would be too big"

Therefore:

The product will not include this feature/component!

Colours

"Do not use neon colours"

"Colourful will be good"

"Capsule, track and frame can be different colours"

Capsules

2nd iterations

Varied textures, contents and content visibility (improve range of stimuli) —— To show staff and determine which to develop further

Completely clear capsule

Partially clear capsule with textures on side

Partially clear capsule with outer layer of texture

Completely solid textured capsule

Beads inside (auditory stimulus)

Beans inside (auditory stimulus)

Beads inside (auditory stimulus)

Screws inside (auditory stimulus)
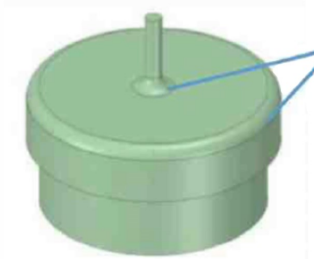
Rounded sharp edges

CAD models enabled dematerialisation (entire cap is one solid

More options and variations in features would be needed

Having all variations above available to children would be beneficial!

Feedback
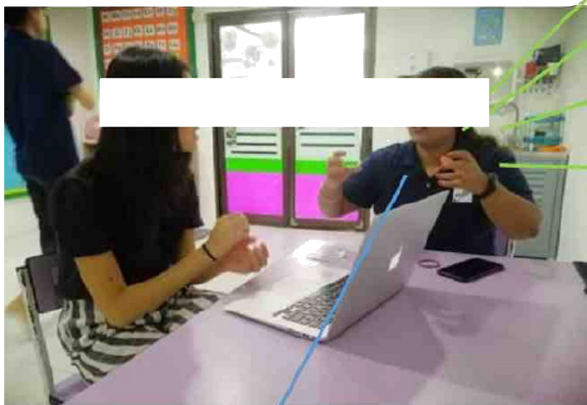
Staff responded: Having variety of capsule designs is actually desirable

Children love capsule's wealth of sensory stimulus—not overwhelming

Held their attention for much longer than typical attention span

"Size is perfect: capsule size allows children to practice grip"

Children want to feel textures not just with hands

"3 different capsules would be good"

Capsule needs to be safer for use outside frame

"Better for children to see contents, for visual stimulation" - Staff

Capsules are easily opened / removed from track by children

Capsule support rods were broken due to their thinness

Staff: other possible contents— rice, marbles, coins, stones

Material needs to be durable: PLA would be suitable

Non-interchangeable contents, so children will not try to remove contents

3rd iteration of capsules was designed alongside track (next page)

Tracks and Frame

2nd iterations

Need sensory stimuli, but also to learn cause and effect ➡ Tracks of different difficulty and tactile stimuli, requiring different skills

Changing direction of track increases difficulty from original

Extensions with nobs require problem-solving to navigate (even more difficult)

1

2

3   4   5   6   7   8

Feedback

Provide sensory stimuli, and teach cause and effect/ problem-solving

"More complex tracks are more desirable" - Staff

"First model's track (Track 4) was too easy"

"tracks 2, 5, 7 (more difficult) would be best—Staff

Sharp corners need to be rounded—dangerous

"3 different tracks would be good"

"Tracks don't need to be interchangeable: embed in frame " - Staff

"Track needs to be redesigned so capsule stays in" - Staff

3rd iterations of frame + track + capsules

Track cavity + support rod head >

Capsule only removed through mechanism

Track cavity + support rod head >

Capsule stays level + easily moved

Thicker, not easily broken

With these support rods, capsule safer for use outside frame

4th iterations to frame
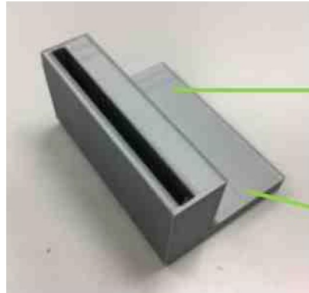
Rounded frame joints ensure safety of children and staff

Makes frame designed for (dis)assembly (frame joints + frame boards)

Final iterations

Added outer grooves to improve strength

3D-printed PLA frame joints

Laser cut MDF boards

Temporarily fixed together using screws

Designed for assembly & disassembly

If damaged, can replace individual part instead of whole product
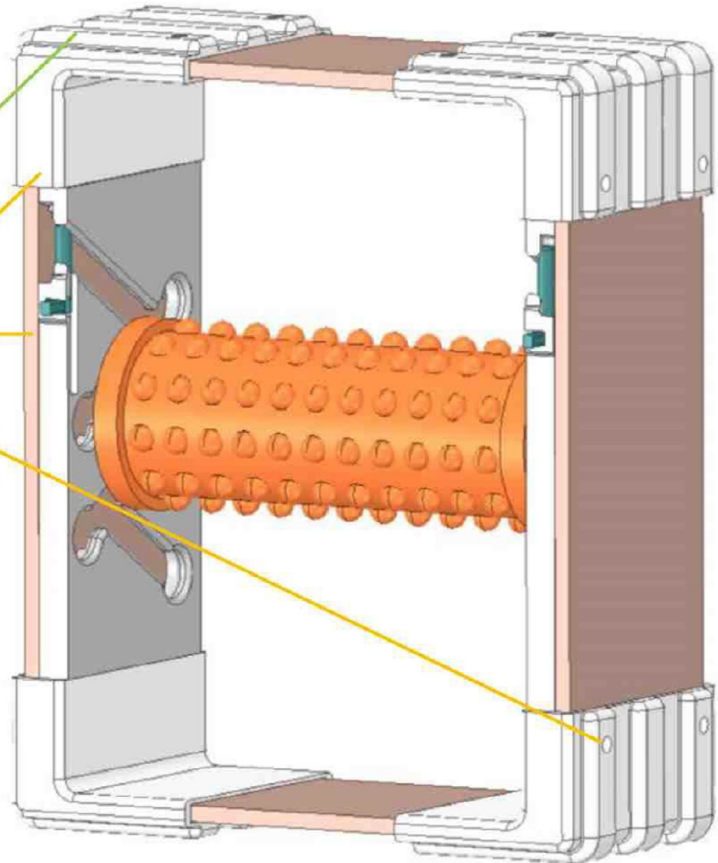
Exploded assembly drawing of track, capsule, joint (without MDF boards)

Track secured in joint to minimise shifting of components

Rounded outer edges of track allows even smoother capsule movement

This system secures capsule and keeps it level during movement
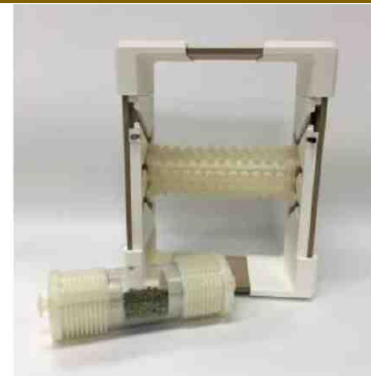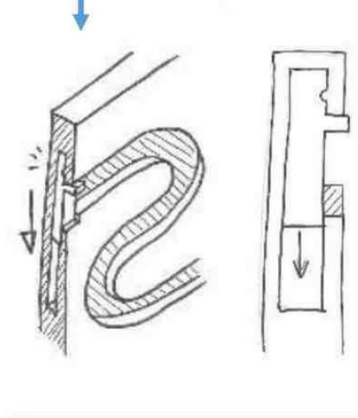
Capsule-changing mechanism

Concepts

Children should not be able to remove capsule → Interchangeable capsules require mechanism simple for staff, difficult for children
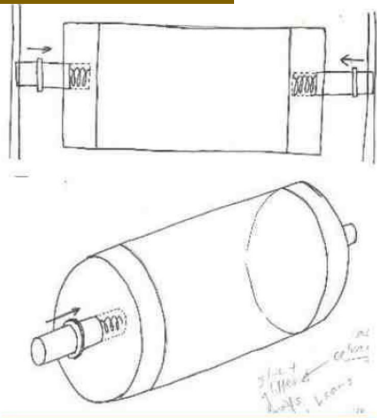
Capsule spring mechanism
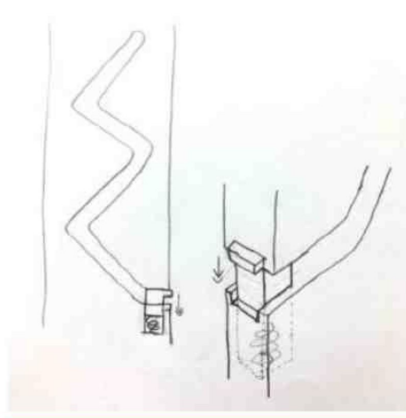
Spring stopper

Locking stopper

Feedback

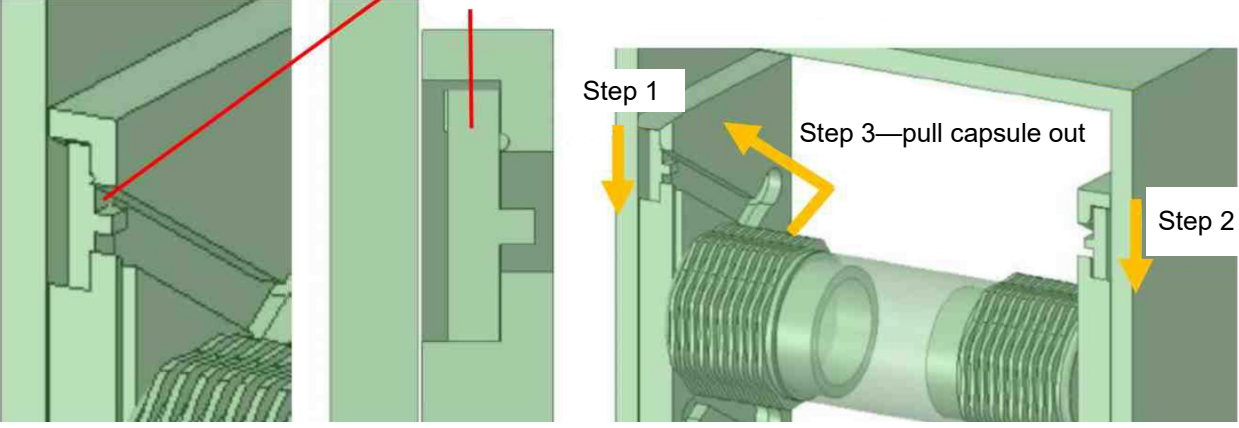Children could learn how to remove capsule accidentally

Would require more than two hands to remove capsule: difficult

Able to shift stoppers separately, then take out capsule

Locking stopper

2nd iterations

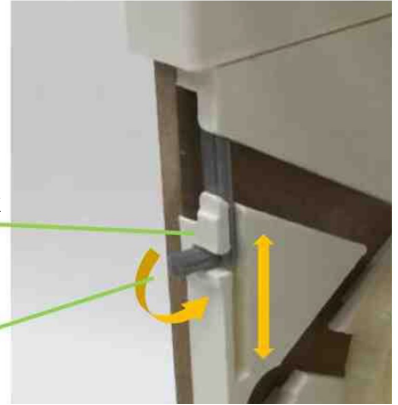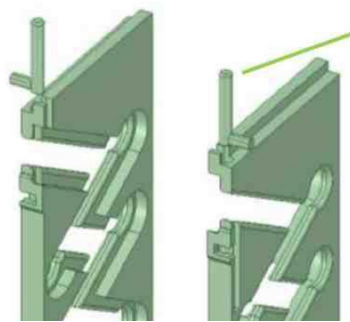All iterations either failed to function or the stopper broke

Step 1

Step 3—pull capsule out

Step 2

Final iteration
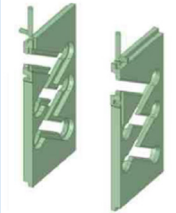
Able to shift stoppers separately, then take out capsule

Friction between stopper and track enables reliable function

Mechanism components are strong enough not to break

Criterion C: Component list

No.	Component Name	Material	Manufacturing process	Image
1	Capsule Head 1	PLA	FDM 3D Print	
2	Twisted Capsule	PLA	FDM 3D Print	
3	Capsule Head 2	PLA	FDM 3D Print	
4	Studded Capsule with one capsule head attached	PLA	FDM 3D Print	
5	Frame joint	PLA	FDM 3D Print	
6	Tracks with Stoppers	PLA	FDM 3D Print	
7	Frame boards	MDF	CNC Router	

Materials selection

3D-Printed Components

	PLA	ABS	TPU95A
Mechanical properties	Durable; tough, not as tough as ABS; may become brittle—4	Strong; tough; durable - 5	High impact strength; resistant to wear & tear - 5
Physical properties	Easy to print; low particle emissions so fit for children—5	Easy to print -4	Easy to print—4
Cost	690 Baht for 1 kg, 1.75mm—5	690 Baht for 1 kg, 1.75mm-5	2200 Baht for 0.75kg, 1.75mm—3
Availability	Readily available in Thailand—5	Readily available in Thailand—5	Readily available in Thailand—5
Finish required	Yes: remove support material + can treat with acetone to smoothen—3		Yes: remove support material—3
Aesthetic Properties	Printed with high resolution / surface quality, different colours, glossy finish—5	Printed with different colours & matte finish - 4	Relative to other materials, lacks aesthetic properties - 3
Based on specification	Waterproof; quite tough —4	Waterproof; tough—5	Waterproof; tough—5
Totals	**31/35**	**31/35**	**28/35**

PLA selected as best material for 3D printing components

Materials selection

Sheet materials for CNC router/Laser cutter

	Blown PVC	**MDF**	**Plywood**	**Acrylic**
Mechanical properties	Tough; durable -5	Fairly hard; can crack or split -4	Strong; durable -5	Strong; durable; easily scratched - 3
Physical properties	Abrasive & corrosive > could damage CNC cutter; lightweight; waterproof - 3	Easily machined; heavy; without finishing, not waterproof -4	Can be water resistant but without finishing, not very waterproof -2	Easily machined; lightweight -4
Cost	1100 Baht for 1200x2400mm -3	149 Baht for 1230x2450mm -5	480 Baht for 1220x2440mm -4	1990 Baht for 500x300mm -2
Availability	Readily available in Thailand-5	Readily available in Thailand-5	Readily available in Thailand-5	Available in Thailand -4
Finish required	No; can be sprayed -5	No; easily painted / stained -5	Yes; easy and ready to finish with paint/ stain -3	No; can be painted / sprayed -5
Aesthetic Properties	Limited colours; smooth surface; rough edge -3	Smooth surface; easily painted / veneered-4	Splinters when routed; rough edge -3	Many colours; smooth surface; rough edge -4
Based on specification	Waterproof; tough - 5	Not waterproof without finishing; quite tough -3	Not waterproof without finishing; quite tough -3	Waterproof; tough - 5
Totals	**29/35**	**30/35**	**25/35**	**27/35**

MDF selected as best material for routed components

Feasibility of Manufacturing processes

	FDM 3D printing	Laser cutting	CNC router	Hand / Machine tools
Complexity	Complex shapes in xyz-axes -5	Complex shapes in xy-axes, layers needed for z-axis -3	Complex shapes in xy-axes; limited complexity in xyz-axes, layers needed - 3	Complex shapes (in xyz-axes) - 5
Cost	Considerable initial startup cost; materials used may be expensive—3	High initial startup cost; low unit cost —3	High initial startup cost; materials used like MDF are inexpensive—4	Can be fairly in-expensive—5
Skill required	High level of skill required to create drawing—3	High level of skill required to create drawing—3	High level of skill required to create drawing—3	Extremely high level of skill required—1
Availability	6 3D printers -5	1 Laser Cutter available -3	1 CNC Router available -3	Abundant tools -5
Repeatability	Can produce same parts repeatedly once programmed—5	Can produce same parts repeatedly once programmed—5	Can produce same parts repeatedly once programmed—5	Difficult to reproduce parts exactly—2
Accuracy	High accuracy —5	High accuracy —5	High accuracy —5	Limited accuracy compared to CAM —2
Finish	Post-manufacturing finishing usually required, like to remove supports—2	High quality; no post-manufacturing finishing needed—5	High quality; no post-manufacturing finishing needed—5	Finishing typically required—2
Waste	Additive manufacturing produces very little waste—5	Need to tessellate shapes on sheet to reduce waste—2	Subtractive manufacturing causes considerable waste—2	Likely produces con-siderable waste - 3
Materials	Several types of plastics—4	Sheet materials: Polymers, maxi-mum 7mm thick; Timber, maximum 5mm—1	Sheet materials: Several plastics, woods; maximum thickness = cutter depth (-15mm) - 4	Almost limitless range of materials, including woods, metals, plastics —5
Time	Can take considerable time to print a part—3	Cuts quickly once programmed—4	Cuts quickly once programmed—4	Takes a long time to produce a part —1
Totals	**40/50**	**34/50**	**38/50**	**31/50**

FDM selected as most appropriate for product

Joining processes

	Adhering	Fusing	Nuts & bolts / screws
Accuracy	Surfaces / parts are marked and adhered manually, potentially lowering accuracy—3	Surfaces / parts are marked and fused manually, potentially lowering accuracy - 3	Holes and marks created by CNC or FDM printing—5
Cost	Very inexpensive—5	Tools required can be fairly expensive—3	Very inexpensive—5
Skill required	Skills required to adhere accurately and adequately - 4	Skills required to operate fusing tools safely and accurately—3	Skill required to mark and create holes - 4
Availability	Very available in Thailand with local shops of many sizes—5	Available in Thailand with multiple local shops—4	Very available in Thailand with local shops of many sizes—5
Suitability for chosen material	Suitable for permanently joining capsule components to keep fillings in—5	Fusing not necessary; simpler joining processes are adequate—5	Temporary joints allow design for (dis)assembly of components—5
Totals	**22/25**	**18/25**	**24/25**

Screws and adhering selected as most appropriate for product

I chose PLA for 3D printing. Though it scored the highest alongside ABS, PLA was chosen for its attractive (glossy finish) aesthetics properties and safe (high surface quality) for the children. Furthermore, PLA has low particle emissions, important for the children at the centre who might bite or chew on the product. PLA is durable enough to withstand wear and tear from use.

I chose MDF for the CNC router sheet material. It scored the highest. Though blown PVC scored slightly lower, I still chose MDF as it is heavier. This is important for the function of the product - it needs to be weighted, especially when children are moving capsules upwards along the track. MDF is not waterproof, however it can be finished to be water-resistant. Furthermore, it is inexpensive, available and easily machined.

I chose FDM 3D Printing and CNC Routing for manufacturing. These processes scored highest out of the four. Hand or machine tools would not be practical - it would take longer to produce the complex components. FDM 3D-printing does this in a much shorter time, to an excellent degree of accuracy, and with minimal waste.
Since the frame boards need to be 6mm thick, laser cutters would not be desirable (unable to cut timber thicker than 5mm). CNC routers are able to quickly manufacture the frame boards.
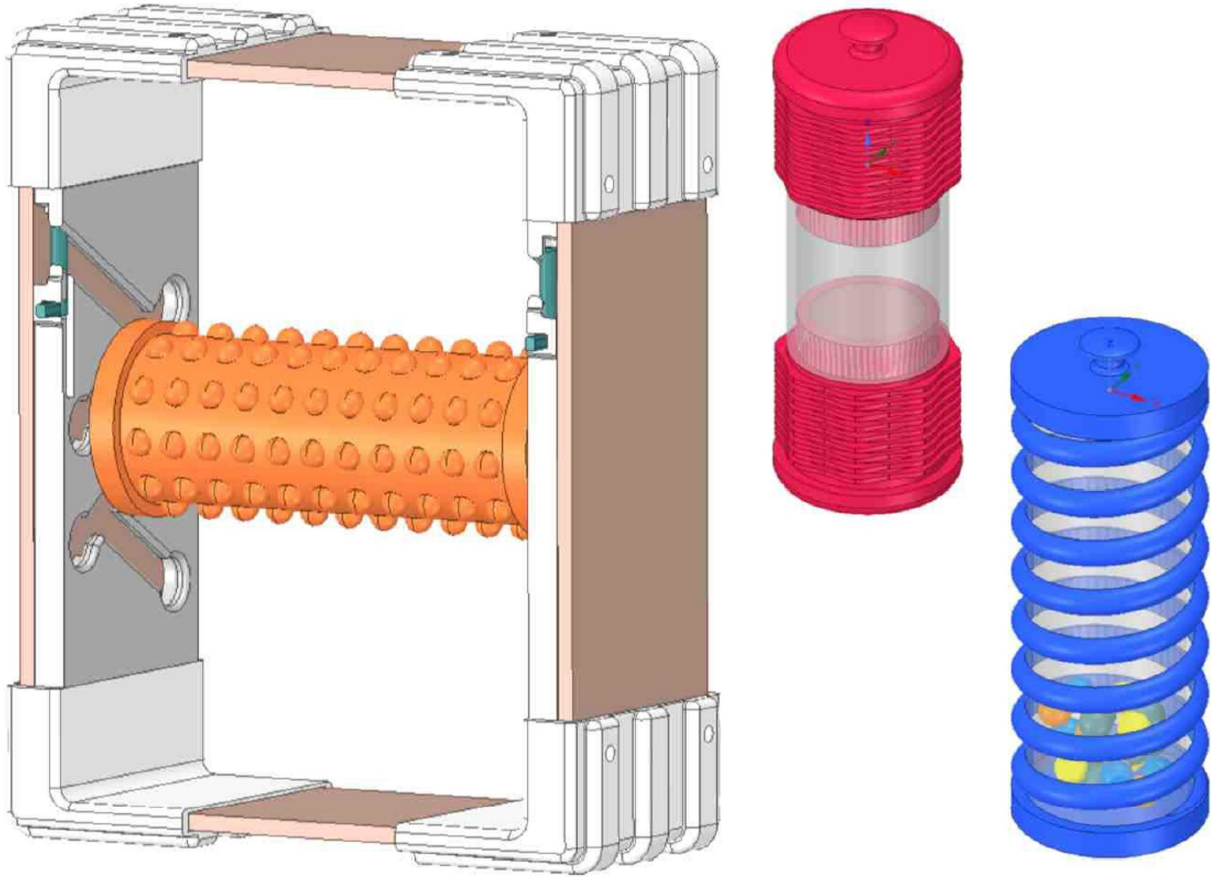I used FDM to print most components, and CNC routing to cut the frame boards. There were many more FDM printers available, as compared to the one CNC router. Hence, I used mostly FDM to minimise lead time (and reduce waste).

I adhered the capsule components together with glue. The capsules contain beans, beads and screws to generate interesting sounds. It was vital that the permanent yet simple, practical process of gluing was used, to ensure no fillings leave the capsule (safety / choking hazards). Fusing would be overcomplicated and unnecessary for this context. I slightly adhered the tracks to the frame boards with double-sided tape too, to secure the track without completely permanently joining it to the frame board (for design for (dis) assembly).
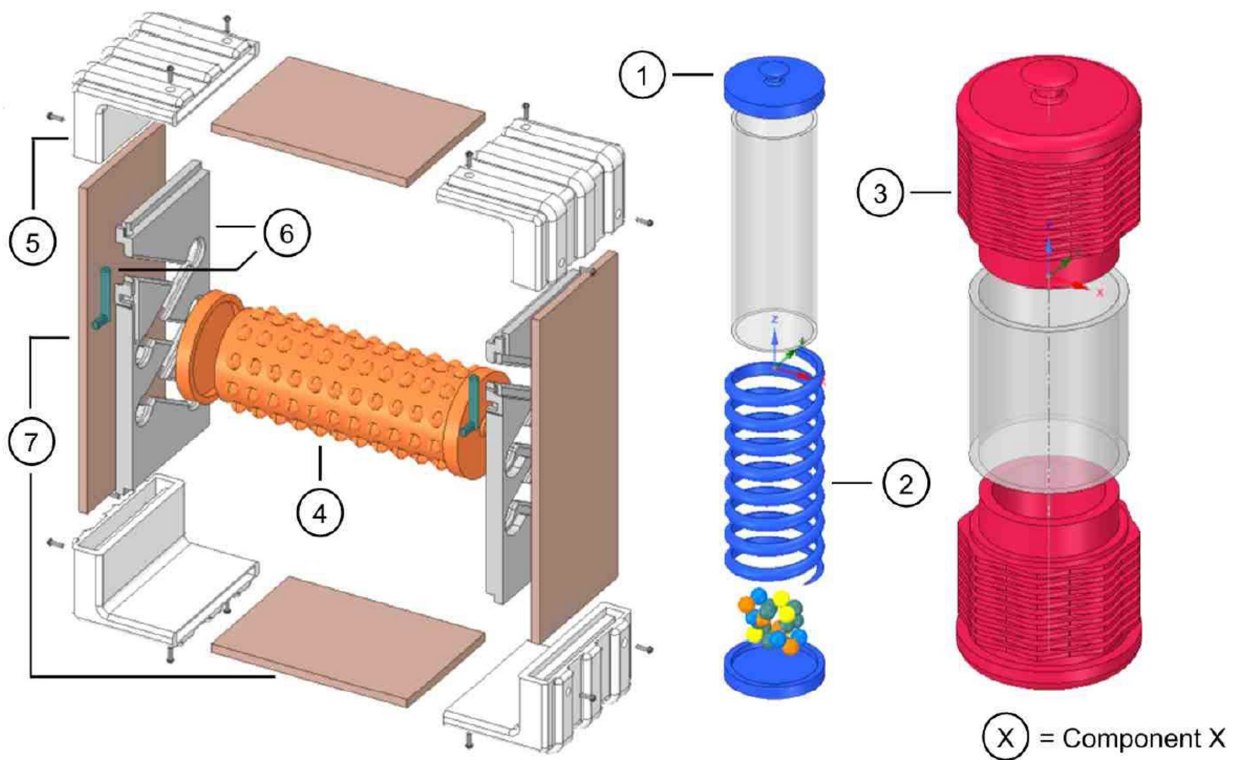I used screws to temporarily join frame joints to frame boards. If any component needs replacement, the screws can be easily removed and the product can be completely disassembled, components replaced, and the product can be put back together again. Adhering and screws scored the highest.

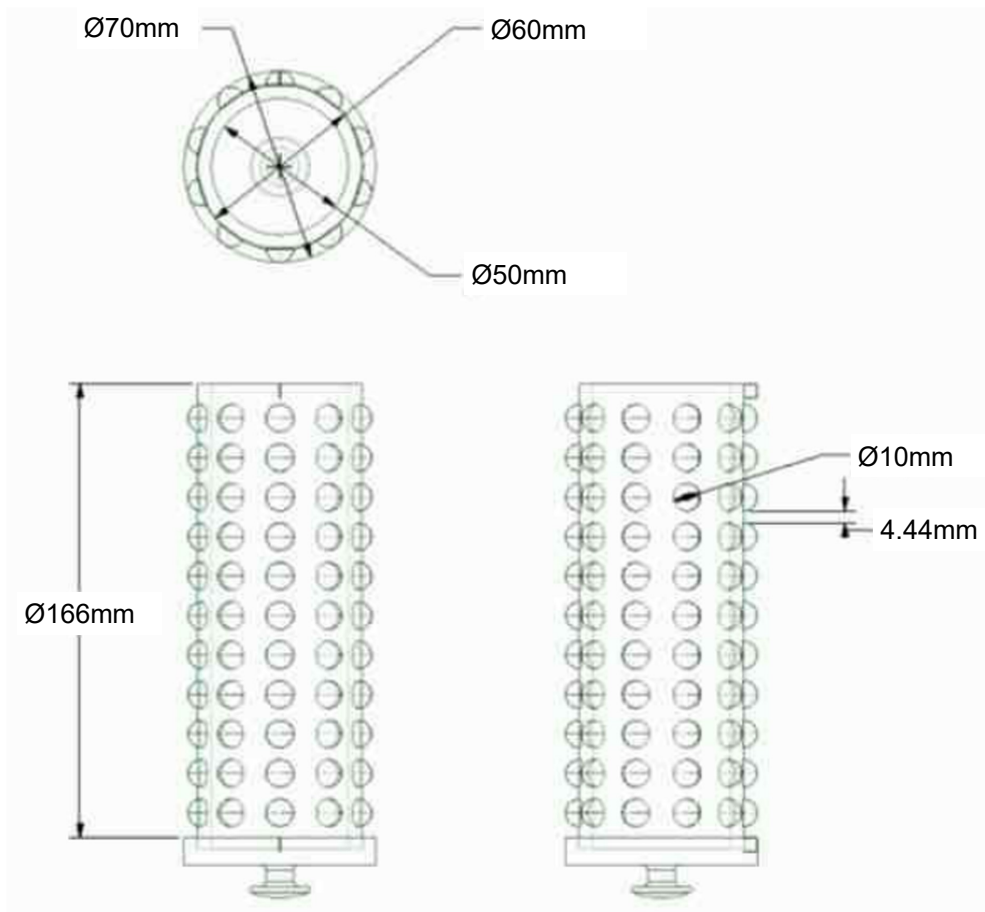(392 words)

Final Detailed Rendering of Product

Exploded View of product
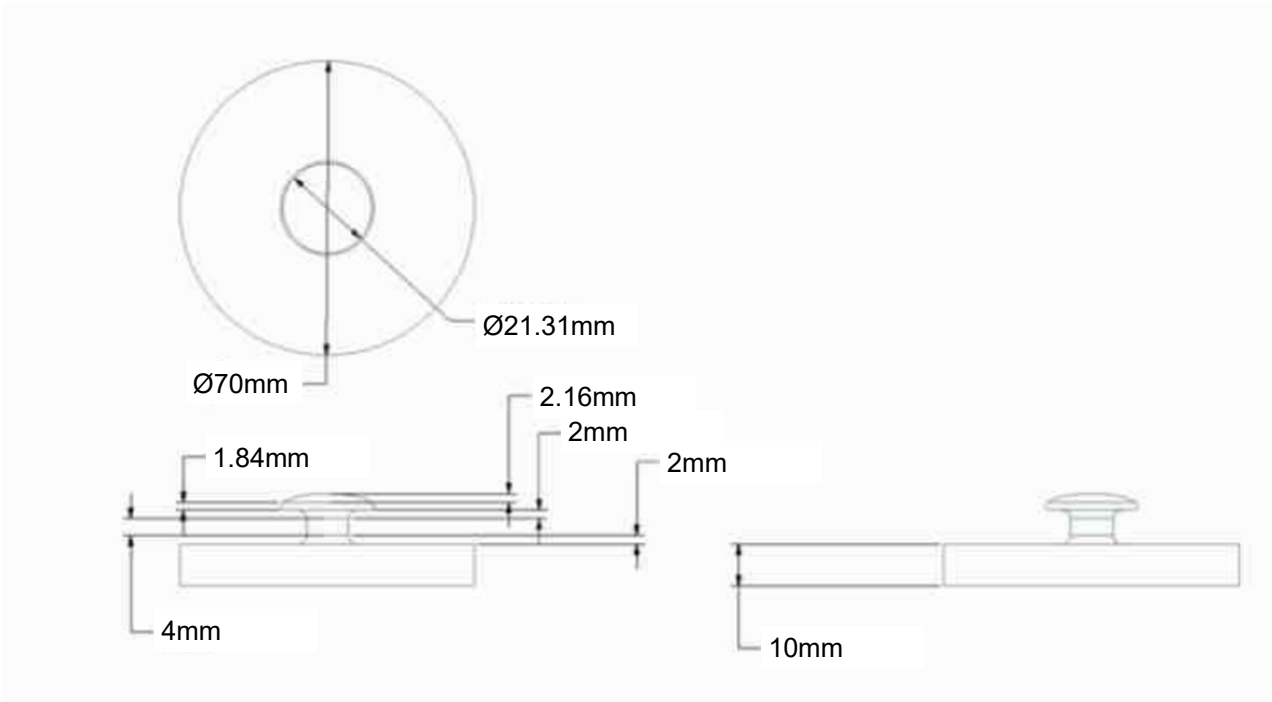
(X) = Component X

Orthographic drawings of individual components

Ø21.31mm

Ø70mm

2.16mm
2mm
1.84mm
2mm

4mm

10mm

Ø70mm   Ø60mm

Ø50mm

Ø10mm

4.44mm

Ø166mm

Orthographic drawings of individual components

Ø70mm

Ø60mm

Ø21.3mm

2.44mm

2mm

Ø70mm

5mm

5mm

44.5mm

14mm

Ø53mm

Ø60mm

78.5mm

Ø3mm

107mm

Ø6mm

Ø10mm

R5mm

R5mm

73.5mm

78.5mm

51mm

56mm

Orthographic drawings of individual components

5mm

97mm

R3.5mm

6mm

6mm

96mm

13.86mm

18.85r

R13mm

R11mm

R9mm

4.23mm

18.5mm

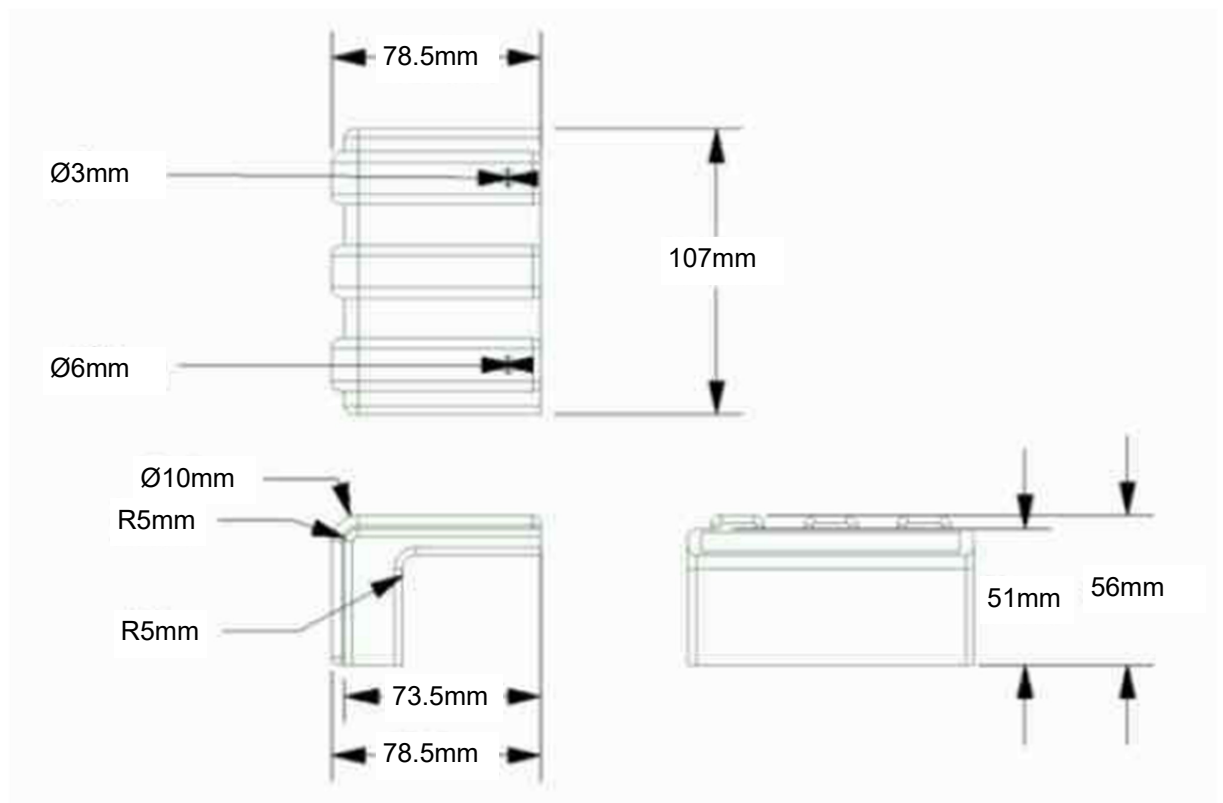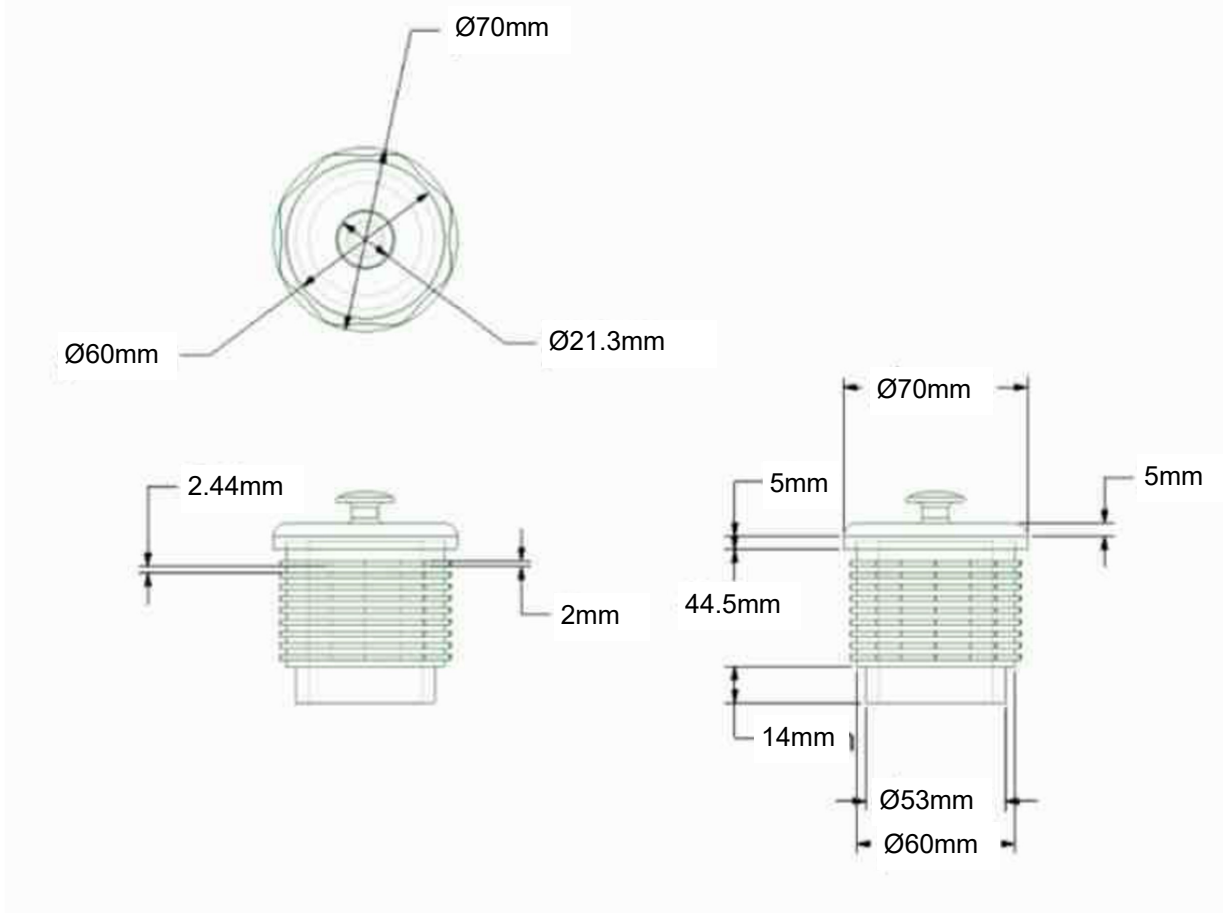47.56mm

40.63mm

232mm

140mm

96mm

96mm

6mm

Orthographic drawings of individual components

9.88mm

Ø4.25mm

Ø6.25mm

1mm

36mm

5mm

3mm

Ø60mm

161mm
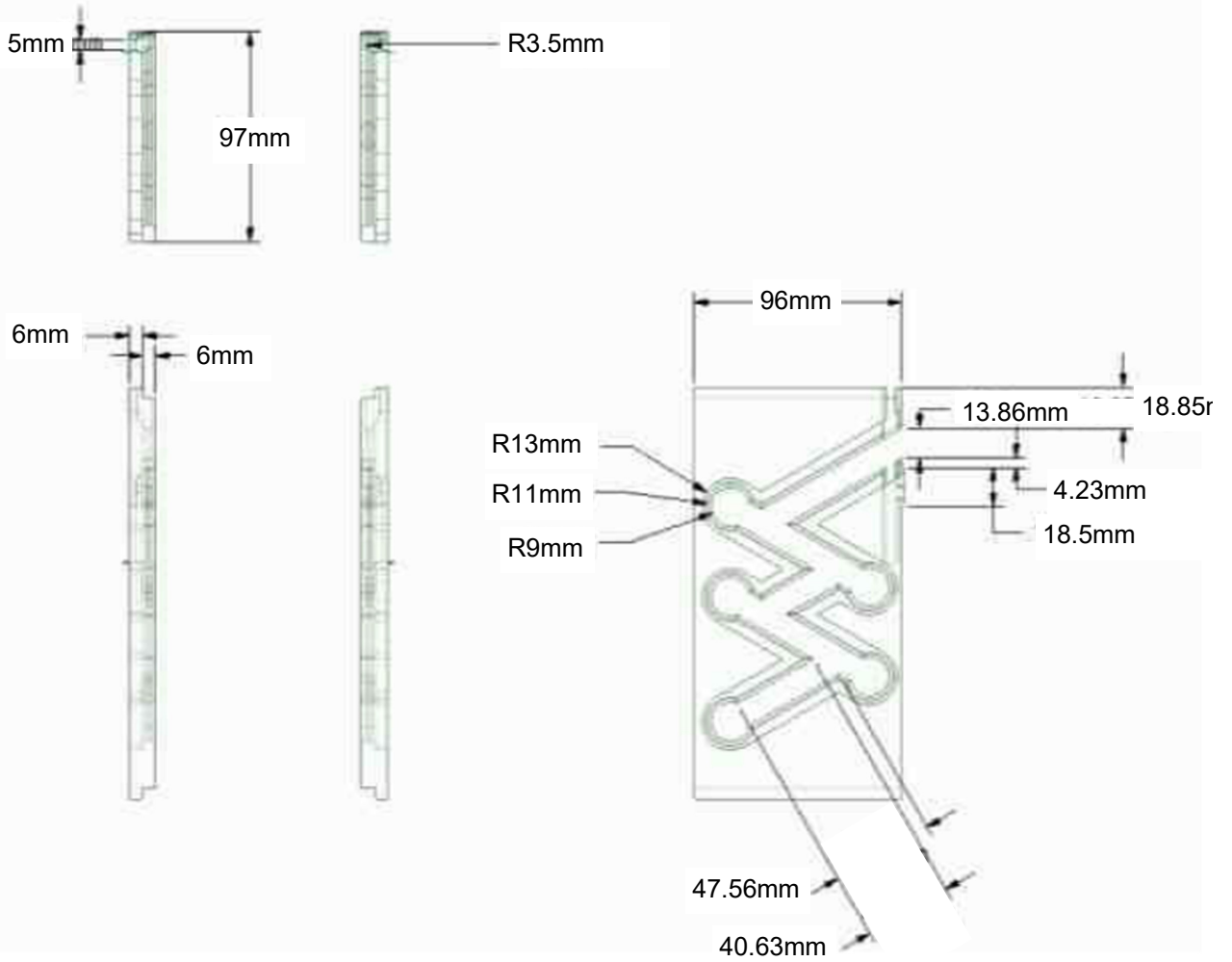
Bill of materials

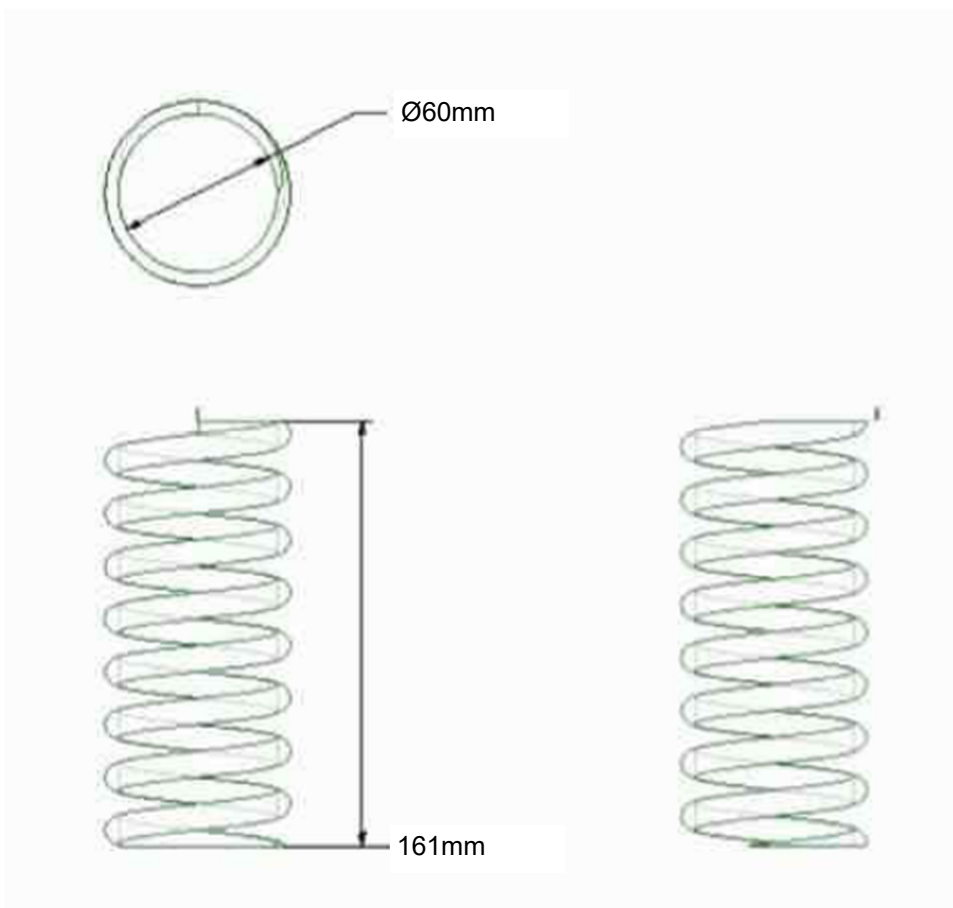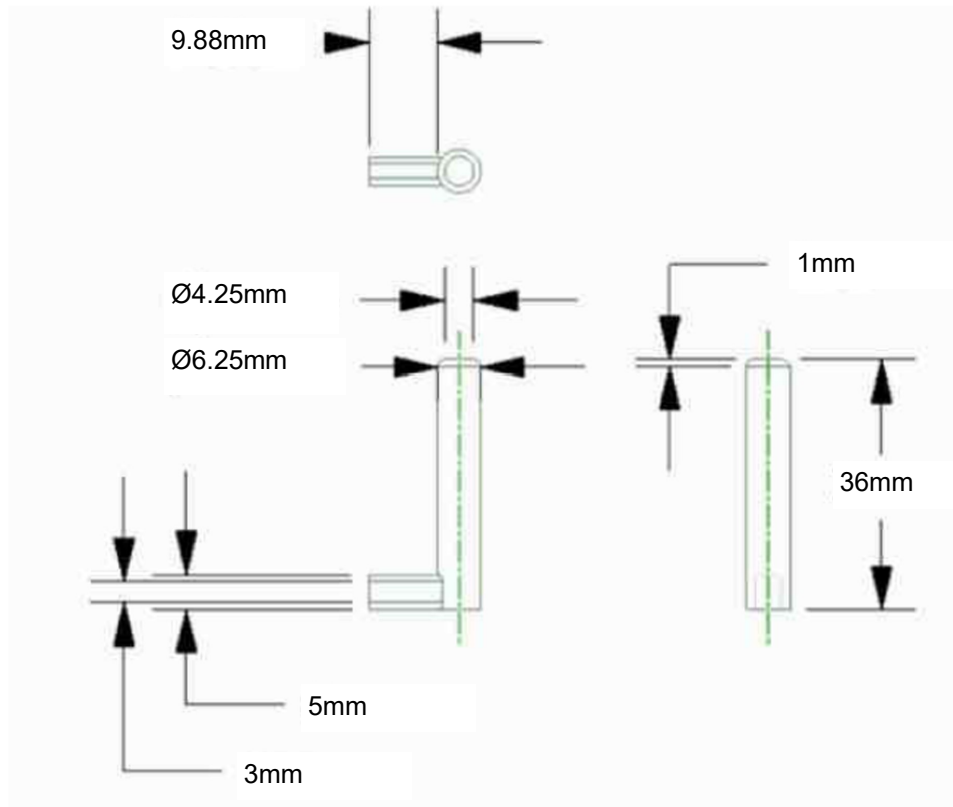|	Component	Material	Size	Quantity	Finish	Cost
1	Capsule head 1	Polylactic acid (PLA)	19g per	3 x 19g	Remove support material: can treat with acetone to smoothen surface	1kg = 690 THB 1.073kg (total PLA required) = 740 THB
2	Twisted capsule		59g per	1 x 59g		
3	Capsule head 1		76g per	2 x 76g		
4	Studded capsule with one capsule head attached		200g per piece	1 x 200g (=200g)		
5	Frame joint		111.2g per piece	4 x 111.2g (=445g)		
6	Tracks with		80g per	2 x 80g		
7	Frame boards	Medium density fibreboard (MDF)	140x96mm 232x96mm	2 x 130g + 2 x 220g (=700g)	Sand edges	14kg = 149 THB 0.7kg = 7.45 THB
8	Screws	Stainless Steel	4x10mm	16 pieces (pcs)	-	40 pcs = 150 THB 16 pcs = 60 THB
9	Silicone Glue	Silicone	-	1 tube	-	1 tube = 100 THB
10	Pipe	Clear acrylic	60mm outer diameter, 3.5mm thick	250mm long tube	Sand edges	1mm tube = 717 THB 250mm = 179 THB
	Total cost					Approx. 1090 THB

Construction Plan

Processes	Equip-ment	Scheduling	Quality control	Risk assessment
Create SpaceClaim files (besides frame boards): send to FDM printer	Desktop, FDM printer	6 hours	Ensure dimensions are accurate: print right number of each component	No risk
Create 2D Design file (frame boards): send to CNC router	Desktop, CNC router	10 minutes	Ensure dimensions are accurate: print right number of each component	No risk
Manufacture SpaceClaim CAD files using FDM 3D printer	FDM printer	5 days	Monitor 3D printer to check for misalignments mid-way through manufacture	** Heated print bed / nozzle / motors could cause burns Ensure print bed, nozzle, motors have cooled before touching printer Place printer in enclosed space to minimise hazardous contact
Manufacture 2D Design CAD files using CNC router	CNC router	30 minutes	Monitor CNC router to check for misalignments mid-way through manufacture	** One could be accidentally cut by cutter * Cutter could cause dust and 'throw' material Wear glasses and define workspace around machine early
Finish components e.g. remove 3D printed support materials, sand	Hand tools, sandpaper	1 hour	Check all edges / gaps to ensure smooth surfaces for children	** Sharp tools can easily cause cuts Wear gloves when working with sharp tools
Screw 2 frame joints to 1 shorter frame boards (x2)	Screwdriv-er, screws	20 minutes	Ensure screws are accurately posi-tioned & secure	** Sharp tools can easily cause cuts if stepped on
Enclose longer frame board & track within frame, screw together	Screwdriv-er, screws	5 minutes	Screw accurately & securely: minimise gap between components	Return all screws and screwdrivers to assigned place once done
Assemble capsules adding fillings as desired/needed	Silicone glue or hot glue gun	1 hour	Ensure tight and neatly glued	* Glue could enter eye and cause severe injury Avoid touching eyes while working with glue ** Heated nozzle & glue could cause burns Wear gloves
Total	-	~ 6 days	-	-

Process for the completion of all 3D prints

| Save completed design as either .obj or .stl file | → | Open 'Cura' and drag file onto 3D printer bed | → | Orientate onscreen model into correct position | → | Set layer height and % infill |

| 'Slice' the model and save onto the USB | → | Plug in the USB > Select file > Print | → | When complete, remove model from printer | → | Remove breakaway support materials |
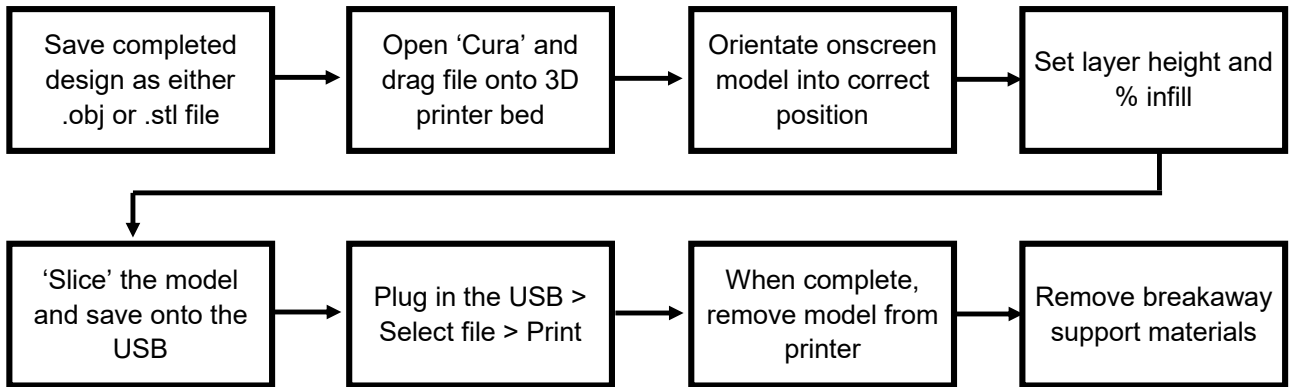
Comp	No.	Grams/print	Time	Layer height	Infill (%)
1	3	57g (3 per print)	4h 23min	0.2	40
2	1	59g	4h 48min	0.3	20
3	2	152g (2 per print)	11h 33min	0.3 Higher layer height for aesthetic qualities	40
4	1	200g	15h 7min	0.3	40
5	4	445g (4 per print)	1 day 6h 55min	0.2	20
6	1	80g (1 track + 1 stopper	6h 8min (per print)	0.2	40

Higher **layer height** & surface finish > lower speed of print

I lowered layer height to 0.2mm for most components

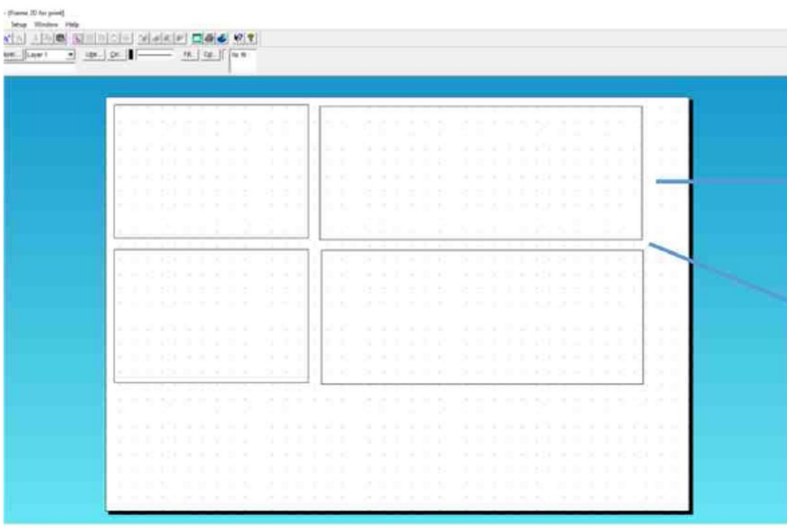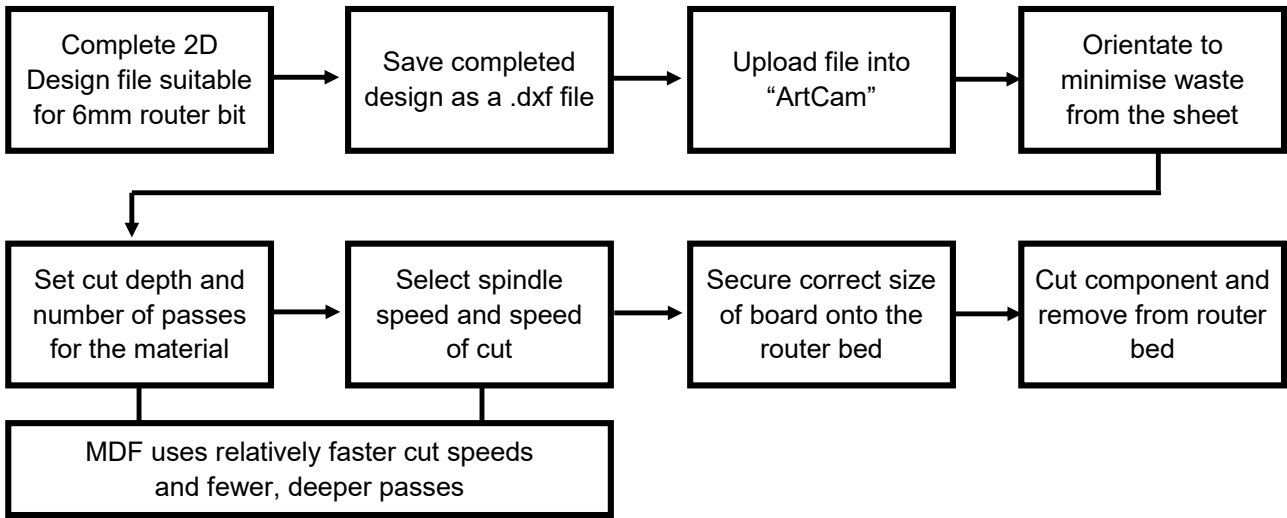Allows faster print without overly compromising on surface finish

Medium, **20% infill** allows reasonable durability

Higher % **infill** for these components, which rub against each other

Print time & component weight listed

Process for the completion of router-cut parts

Complete 2D Design file suitable for 6mm router bit	→	Save completed design as a .dxf file	→	Upload file into "ArtCam"	→	Orientate to minimise waste from the sheet

Set cut depth and number of passes for the material	→	Select spindle speed and speed of cut	→	Secure correct size of board onto the router bed	→	Cut component and remove from router bed

MDF uses relatively faster cut speeds and fewer, deeper passes

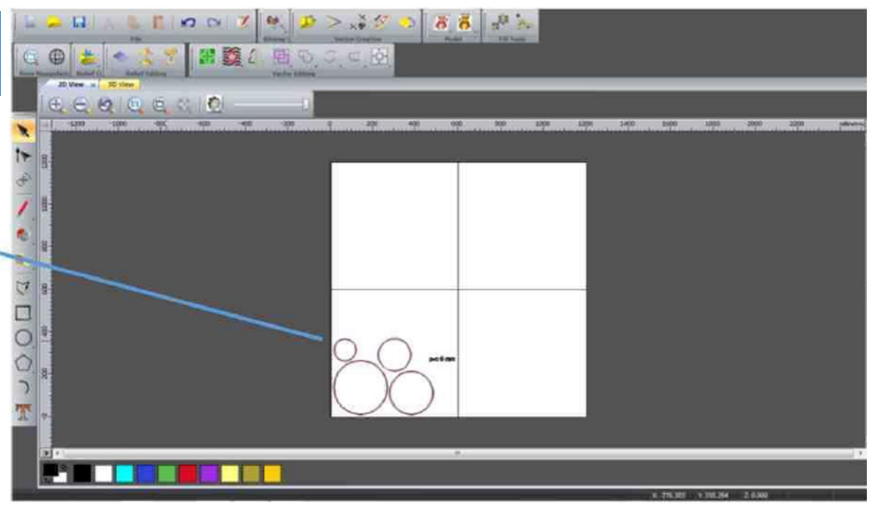**2D Design file for frame boards**

Layout minimises waste

Gap between pieces = 6mm (school router uses 6mm cutting bit)

Reduces amount of cuts > less energy used

ArtCam file

Would be replaced with layout from above picture

Criterion D: Strategies for Testing

User Trial—Observation

Ref:	Success parameter	Tested with	Justification
UT1	Observe whether children gain various sensory stimulation from using product	Primary user	Product needs to introduce range of sensory stimuli to children
UT2	Observe children's length of engagement with product	Primary user	Staff stated 10-minute-long engagement shows product holds child's attention well
UT3	Observe whether children are distressed emotionally during use	Primary user	Product must not distress children, especially with their developmental disorders
UT4	Observe children's ease of use of product	Primary user	Product must be simple enough for children to manipulate
UT5	Observe if children learn effects of different manipulations of product	Primary user	Product should show user some cause and effect
UT6	Observe children's hands: get trapped inside gaps / touch sharp edges?	Primary user	Product has to be safe for 6-to-9-year- old children

User trials carried out with children and Staff at educational centre

Performance Testing —Quantitative Data

Ref:	Success parameter	Method	Justification
PT1	Measure durability and lifespan of locking mechanism (vulnerable component)	Operating locking mechanism 50 times repetitively	Product must be able to be used many times
PT2	Measure toughness of product	Drop parts repetitively and observe for crack propagation	Product must be tough to withstand impacts of daily use

Performance Testing was carried out in my school workshop.

Criterion D: Strategies for Testing

Expert Appraisal—Interviews

Ref:	Success parameter	Tested with	Justification
EA1	Specific feedback on functionality of design	Director of the centre	Director is an expert in working with the primary users

Expert Appraisal was carried out at the village educational centre.

Field Trial—Observation at the village centre

Ref:	Success parameter	Tested with	Justification
FT1	Observe staff setting product up for use	Staff at the centre	Staff must be able to change capsules in 60s
FT2	Observe if product can be stored effectively indoors	Staff at the centre	Product must be able to stored in the centre
FT3	Observe staff cleaning product	Staff at the centre	Product has to be hygienic for children to use

Field trials carried out at the village educational centre

Comparison—Compare with similar products

Ref:	Success parameter	Tested with	Justification
C1	Compare price of product to similar existing products	Literature search	Needs to compare favourably with similar products cost-wise

Comparisons were conducted using the internet

These testing methods were used to evaluate the functionality and suitability of the product to the primary users. Some of the children and staff from the village educational centre visited my school, during which I carried out some observational trials and expert appraisal.

Afterwards, I went on my fourth visit to the centre, where I conducted field trials, user trials and expert appraisal with the staff and the children I have been working with, namely QQ, T, S and M.

I also carried out physical performance testing in my school workshop and did comparison tests via the Internet.

Evaluation Against Specification

Specification	Test Ref.	Rating	Comment
Must introduce sensory stimuli, holding their attention without distressing them	UT1 UT2 UT3	4/5	Children gained auditory, visual and tactile stimuli from interacting with the product. They were emotionally stable while using it, and seemed delighted by the stimuli. Though distracted at times by other toys in the room, they were mostly continually, deeply engaged.
Should show user some cause and effect	UT1 UT5	4/5	Children learned that pushing the capsule vertically, horizontally and diagonally along the track caused it to move within the frame. They learned that spinning the capsule provided sensory stimuli. They learned that by letting staff operate the product, the capsule inside the track could be changed.
Must be able to be stored	FT2	5/5	Staff will store product in an enclosed classroom on a shelf.
Must be simple enough for children and staff to operate	UT4 FT1	3/5	Children naturally spun capsules. However, only 2 children could move capsules along the track, being more advanced in their development. Staff interchanged capsules within a minute, but struggled with the locking mechanism when the stopper got caught. They had to hold the frame down with one hand.
Must be able to perform task many times	PT1	5/5	Main vulnerable part, locking mechanism, remains in good condition after testing.
No sharp corners / edges	UT6	4/5	MDF frame board, track and stopper edges can be sharp, however children were not inclined to touch those edges. Other components are rounded well.
No detachable parts small enough to fit in mouth	-	5/5	No components are small enough to fit in the mouth.
Must not give off flashing lights / loud sounds	UT3	5/5	No flashing lights / loud sounds from product, children are not distressed by any of the sounds produced.
Must not have bright, strong colours	UT3 EA1	5/5	Children enjoy colours used. The Director of centre, complimented the use of colours, as "red, orange, yellow and green are the first colours recognised by infants".
Provides a range of sensory stimuli for children to experience	UT1	5/5	Children gained various visual, tactile and auditory stimuli through different methods. Visual: visual effect of spinning capsules. Auditory: sounds from fillings when capsules are spun. Tactile: capsule textures and act of spinning.
One-off / batch production	-	5/5	Full prototypes were produced one-off. They were also produced in different colours, using batch production.
Must be able to be within user's reach	UT4	5/5	Size of product and even textures on capsules fit children's static measurements very well. Easy for children to use.
Must be able to be manipulated by children	UT4	4/5	Capsules were spun easily, whether frame was vertically or horizontally oriented. Some found difficulty in moving capsules along track, due to developmental deficiencies.

Evaluation Against Specification

Specification	Test Ref.	Rating	Comment
Can be stored indoors	FT2	5/5	Staff will store product in an enclosed classroom on a shelf.
Waterproof / easy to clean	FT3 EA1	4/5	The Director of the centre, stated capsules can be easily cleaned by submerging in disinfectant water, then hanging out to drip dry. Track and frame joints can be wiped with disinfecting cloth. MDF frame boards are harder to sterilise due to limited water-resistance.
Must be tough	PT2	5/5	After drop test within likely context of product's use, product remained undamaged and stiff.
Must be suitable for users 6-9 years old	UT4 UT6	4/5	Within this age group, some children, due to differences in places on the autism spectrum, find it difficult to grasp the concept of moving capsules along the track. Product dimensions are safe though, ensuring children's hands do not get trapped inside potential gaps.
Must not have unpredictable, changing stimuli	UT3	5/5	Children feel at ease. Stimuli is changed at their control or at the decision of staff to interchange capsules: no unpredictable change.
No "goopy" / sticky textures or persistent sounds	UT3	5/5	Children feel at ease. No such textures or continuous sounds are present in the product. Children control when the sounds are generated by spinning the capsules at will.

Strengths and Weaknesses identified by the Evaluation against Specification

Strengths	Weaknesses
Capsules are easily spun & effectively generate visual, auditory and tactile stimulation. Some children learned new skills through using the product (e.g. how to move capsule along track).	*** Capsules could potentially come apart if the appropriate glue is not used, creating potential safety hazard for children due to the small, sometimes sharp fillings that would be released.
Colours attract children to the product and provide even more sensory stimuli.	*** Staff struggled at times with the locking mechanism as the stopper would get caught at certain places.
Staff understood how to change capsules easily.	*** Staff need to use one hand to hold frame down as it slides when capsule is being moved along track.
Children were visibly enjoying their interaction with the product.	*** Moving capsules along the track is too difficult for some children - not all can benefit from this function.
Product is safe and accurately sized for use by the target group.	** Staff have limited ability to clean MDF frame boards.
Product provides the right amount of sensory stimuli in moderation, keeping children engaged for considerable periods of time without distressing them.	* Children can get distracted by other toys, objects or happenings in room easily.
Product is easily stored & mostly easy to clean.	**Key:** *** = most crucial * = least crucial

Evaluation Against Specification

Evidence of testing

FT3
EA1

"We'll submerge capsules in disinfectant water to wash easily" - Director
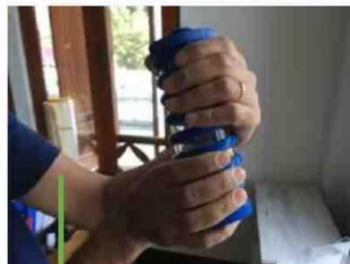
Staff has to hold frame down with one hand

FT1

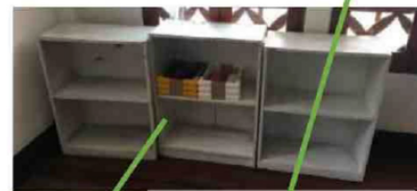"The boards will be more difficult to clean —Director

FT3, EA1

"These colours, the first colours infants recognise are great" - Director

"The textures are perfectly sized—they fit the fingers" - Director

UT1

Easily spun: visual stimuli

Product will be stored on shelf in enclosed classroom

FT2

Children are at ease, engaged and enjoying interaction

UT1 to UT4

PT1, UT5

Child learning how to move capsule along track

However, some other children were unable to grasp the concept
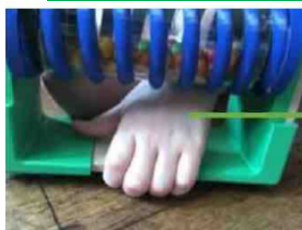
PT1 UT5
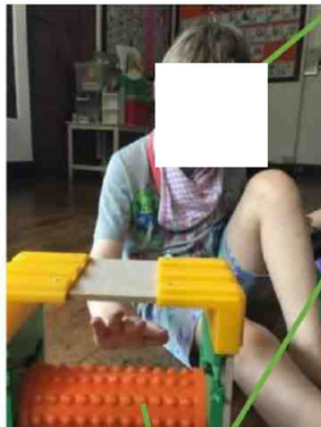
Range of stimuli provided

UT1, UT6

FT1

Staff struggle with locking mechanism as stopper gets caught

Only slight loosening of lock after testing

PT1

Product is safe, does not trap hands inside gaps

UT6

No damage done after drop testing (drops considered classroom use)

PT2

Evaluation Against Specification

Evidence of testing

UT6

Children rarely touched sharp edges: rounded corners were safe

Staff	Staff 1	Staff 2	Staff 3
Time spent changing	27	30	29
Average (Seconds)	28.67		

FT1

Capsules interchanged under a minute

Screenshots from Bill of Materials (Section C)

Total Cost	Approx. 1090 THB

500 THB   400 THB   500 THB

C1

Costs more than 500 Baht (specification)

More expensive than sensory products above, from Section A

1010 THB

C1

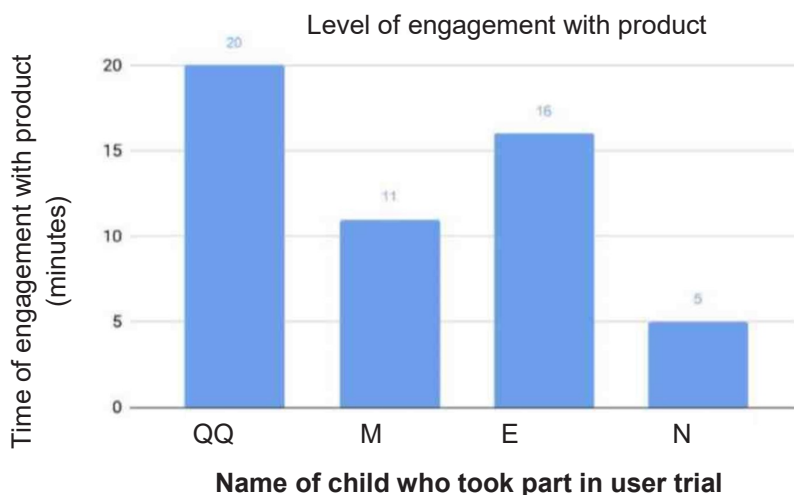Similar price to this product (most similar to my design)

375 THB   365 THB

C1

Costs more than these similar products

Level of engagement with product

Time of engagement with product (minutes)

Name of child who took part in user trial

| **UT2** |
|:-:|

Broadly successful: Most engaged for at least ten minutes

5-minute engagement likely due to N being much younger

Modifications / Improvements

Regarding some children's inability to move the capsules along the track, this is a weakness of the particular track design used in the user trial. However, my design was meant to provide varying degrees of difficulty, and allows tracks to be changed. Hence, for these children with difficulty moving the capsules, an easier track could be used instead. Some examples of easier tracks are on the right.
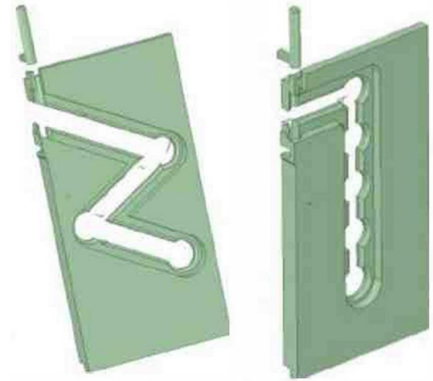
Some weaknesses identified do not need modifications on designer's part

To remove distractions staff should remove or hide objects

Other weaknesses identified can be addressed by specific modifications:

To improve locking mechanism, make the hole for the stopper larger by 0.25mm before printing to allow smoother stopper movement. This is easily managed with CAM.

Use stronger adhesive **to prevent parts and components from separating**

To enable easier cleaning of MDF frame boards, use varnished boards

To address issue that staff need to hold frame down during use, an additional anchor piece could be manufactured:

Suckers to anchor piece down. Inspired by my food processor

*Varnished MDF

3D printed PLA
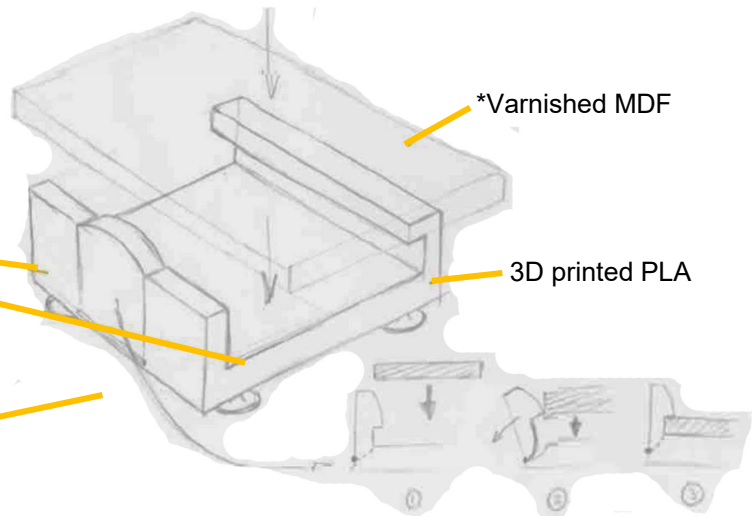
Works both with vertical and horizontal frame orientation
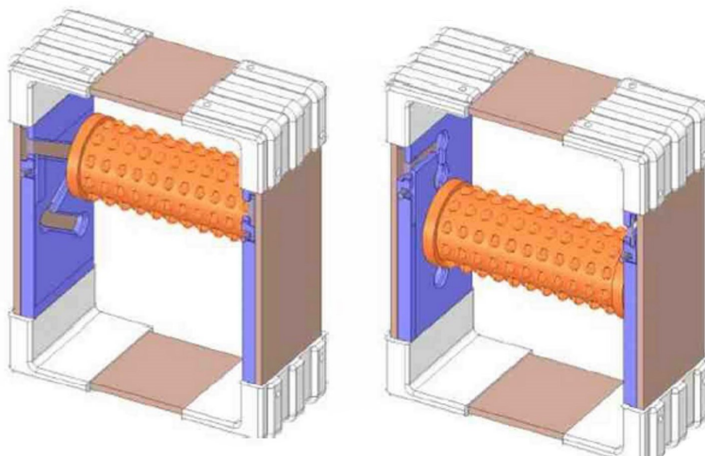
Mechanism which allows easy insertion of frame board into anchor piece, but which then requires additional deliberate action to pull tab back and release frame board. Ensures only staff can remove product from anchor piece.

Full CAD drawings of improved models

(147 words)