silly stompers

Using soft robotics as a medium for gender accessible STEM education of preschoolers

Shreyas Prakash

Silly Stompers
Masters Thesis
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Graduation Committee
Stefan van de Geer
Rob Scharff

Company Mentor
Ellen Pennings

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Last but not least, to the creator of this universe.

This journey on spaceship earth has been great so far.

executive summary

One of the main reasons behind unemployment , income disparities and workplace discrimination against women can be majorly attributed to resource availability. (Ceci, 2011) Among these resources, the development of science and math skills in early childhood through the use of science and math geared toys are considered to be important for 4-7 year olds (Meece, 2006) And disparity in interest towards such toys culminates in the disparity in the STEM professions as such.

If that's the case, how can the disparity be overcome by means of more gender-accessible STEM toys?

To deep dive into this issue, there was an initial research exploration on various concept drivers such as educational play, open ended play, screen free and gender-accessibility itself.

Along this process, various insights were gained on how children think; how do they learn; and what do they play with and so on.

Owing to the closeness to the rationale behind the thesis itself, GENDER ACCESSIBILITY is selected as the key concept driver. In this aspect, the design guidelines needed for gender-accessible design are mapped, and the medium of soft robotics is investigated for it being stereotype independent

In OPEN ENDED PLAY, the philosophy of constructivism is explored with LEGO as a case study. The chapter then goes on to investigate the current trends of LEGO-based, LEGO-compatible toys, STEM toys and how robotics related toys could contribute to the holistic development of the child being inclusive of various pedagogical principles.

In SCREEN FREE, the disadvantages of screen dependence are explored along with the current trend in screen free alternatives for various traditionally digital experiences.

In EDUCATIONAL PLAY, the investigation goes a bit deeper, into the minds of children themselves. How do they think? What do they learn? What do they like to play with? These are the fundamental questions which are explored to shed some insights on the necessary design requirements which can help in ensuring that the designed product satisfies the learning outcomes.

Through brainstorming, ideation and concept generation, the Silly Stompers was chosen for further development through the weighted criteria method. It also fits in neatly into this niche of soft robotics education, and could be a valuable entry into the toy market for 4-7 year olds.

As the research points towards designing a product with an ideal combination of roleplay with constructivist play, it makes for an interesting case of play based learning experience for the kids of this age group.

The story of the Silly Stompers revolves around the ocean bed with these three characters who stomp their way through the ocean bed. As they pump air into the blocks in various sequences, it comes to life and performs various animations through its stomping motion.

Silly Stompers consists of a base which can connect to various soft modular blocks which can perform a wide variety of functions such as to push, to pull, to bend and to extend as well. These blocks can also be stacked with other such blocks creating interesting locomotion patterns through which the children not only learn the basics of soft robotics, but also make sure that they improve on the eight pedagogical principles by doing so (Parker and Thomson, 2019)

In the future scope of development, it could be interfaced with SCRATCH to provide more possibilities through blended learning. Currently, by means of LEGO connectors, it integrates easily with various LEGO building blocks helping in more open ended possibilities.

Through the medium of ScratchBits, it could lead to a more blended making where there are digital instructions which perform physical actions thereby helping make 'coding by means of air' possible.

In this way, Silly Stompers could act as 'wonderful objects' (Hanning, 2016) providing a foundation for participants to explore their own ideas and engage in meaningful and open ended play in a gender-accessible manner.

glossary

STEM - Abbreviation for (Science Technology Engineering and Mathematics)

Research Through Design - Research through Design (RtD) is an approach to conducting scholarly research that employs the methods, practices, and processes of design practice with the intention of generating new knowledge.

Constructivism - Constructivism is a theory in education popularised by Seymour Papert that recognizes the learners' understanding and knowledge based on their own experiences prior to entering school.

Play based Learning - Play-based learning is based on a Vygotskian model of scaffolding where the teacher pays attention on specific elements of the play activity and provides encouragement and feedback on children's learning.

Soft Robots - Soft Robotics is the specific subfield of robotics dealing with constructing robots from highly compliant materials, similar to those found in living organisms.

Pre schoolers - By definition, the age group of pre-schoolers lies in the range of 3-5 years of age. However, since this definition is quite variable around the borders, the wider age group of 4-7 years of age is broadly labelled as pre-schoolers for convenience.

9MOPE - Design method framework taking into account the aesthetic appreciation, construction of meaning and the emotional response while designing the required product experience.

Interconnectors - (Appendix D.4) Used to combine the soft actuator blocks together

Soft actuator blocks - (Appendix D.5) The inflatable hexagonal modular blocks inspired by the design of InflatiBits.

Blended Making - Process of engaging in construction in both the physical and virtual world - and with the interplay between the two.

why this project started

Coming from a background in electronics engineering, and having been involved in pursuing various projects particularly in robotics from my Bachelors, I was always interested in exploring how robotics could be taught to younger children.

However, while I left this interest on the backburner, and found meaning in pursuing Industrial Design at the faculty of TU Delft, I renewed my interest in this after taking the Advanced Concept Design Course for a semester. I was involved in working with Somnox, a company which designs sleep robots for better well being. Through this collaboration, I got interested in the novel domain of soft robots.

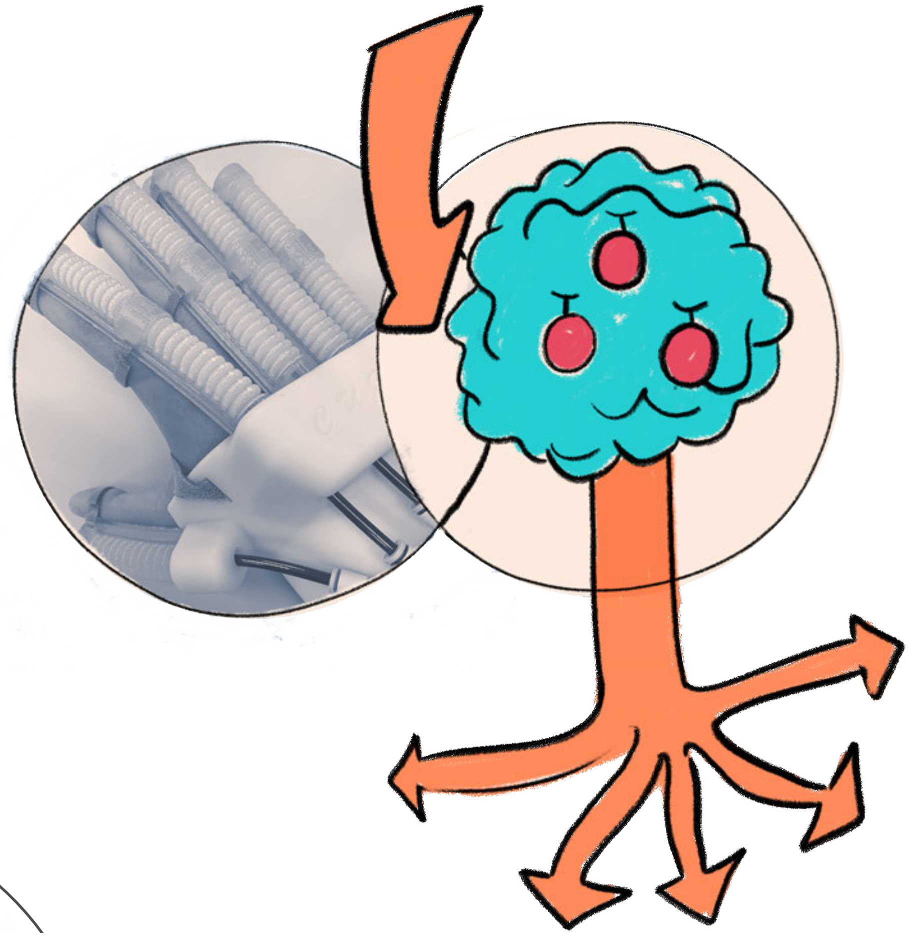
I particularly liked how soft and playful these new robots can be, and that got me thinking about its applications in the education sector.

My interest particularly in this sensitive topic was triggered by a conversation which I was having with a friend of mine who has a doctorate in the field of biotechnology. The conversation revolved around how she could find a lot of gender disparity in the field of biotechnology in itself were women were less represented. And the topic touched upon how skewed up the ratios are, and the need to address the same.

I found this an interesting dilemma to investigate further upon; how can robotics education be made more attractive for both boys and girls? Could soft robotics provide an answer for the same? This was how it all started and how it led me to my further exploration.

The applications of soft robotics particularly in the education sector was looked into with more detail and rigour such as the potential to break way from stereotypes, versatility and how it could provide an enriching tactile experience.

These are looked into with more detail in the upcoming chapters along with a rationale for how it is important to provide gender accessible STEM education for preschoolers.



approach

This project employs a Research Through Design approach where the prototypes used as enquiry tools played a formative role in the generation of knowledge.

As often is the case with RtD, the continuous process of consequent cycles in designing, making, testing and reflecting upon the experiential prototypes in real-life settings forms the main basis. (Stappers and Giaccardi, 2017)

RtD was part of the larger umbrella of the Basic Design Cycle (Roozenburg, 1984) consisting of Analysis, Synthesis, Simulation, Evaluation and Decision Making which is renamed and shown as the three main phases - Explore, Synthesize and Embody.

As the doing style, and enquiry through prototypes was the preferred mode of investigation, the synthesis phase was explored much more extensively through the design of solutions.

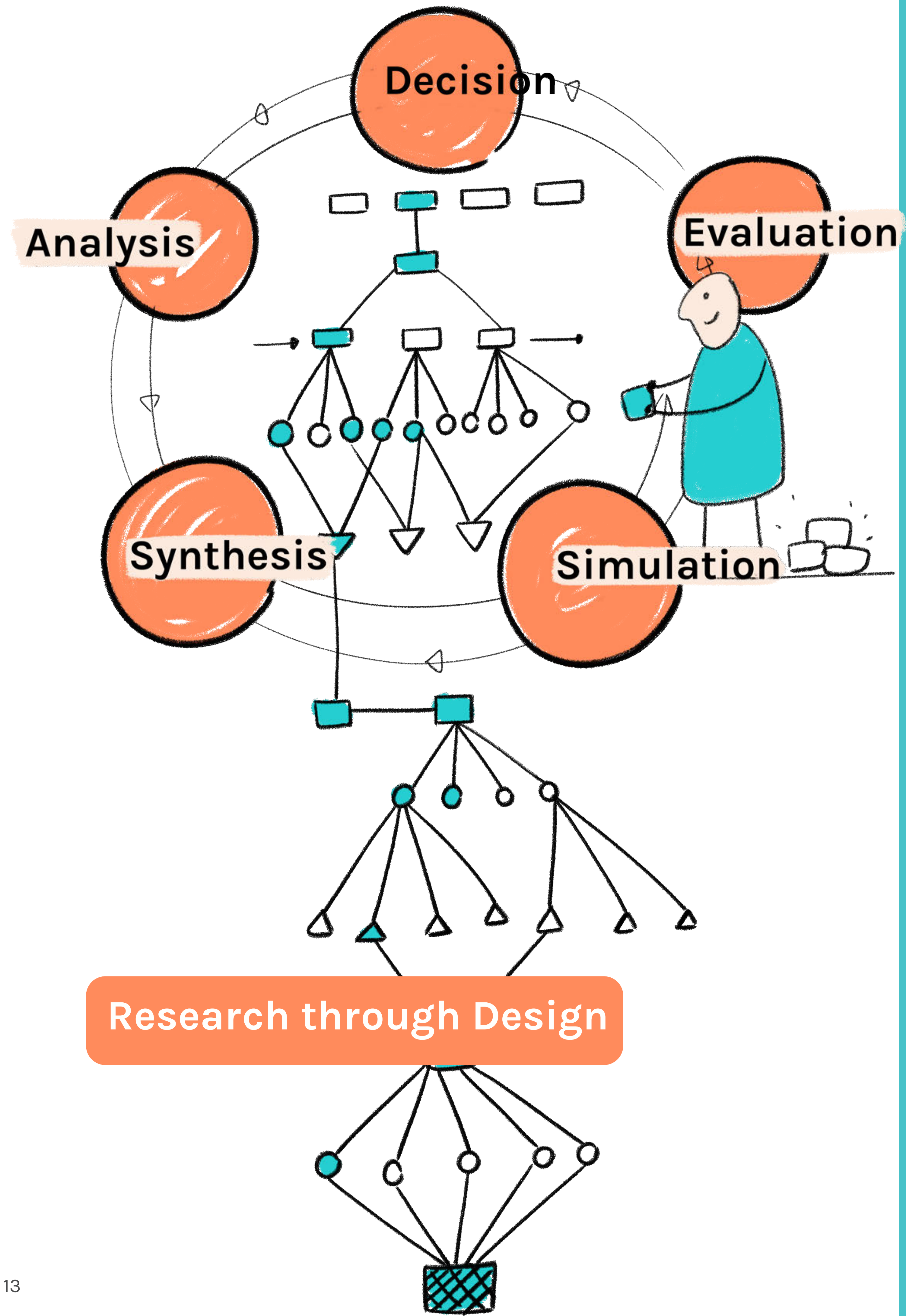


table of contents

explore

synthesize

table of contents

embody

appendix

appendix A

tests and observations

design test 1
design test 2
design test 3
design test 4
conversational interviews

appendix B

design methods

product experience
9 MoPE
moodboard
morphological chart for gestures
color considerations
benchmark analysis
circuit of culture
technicalities and potentialities

appendix C

planning

gantt charts

appendix

appendix D

embodiment challenges

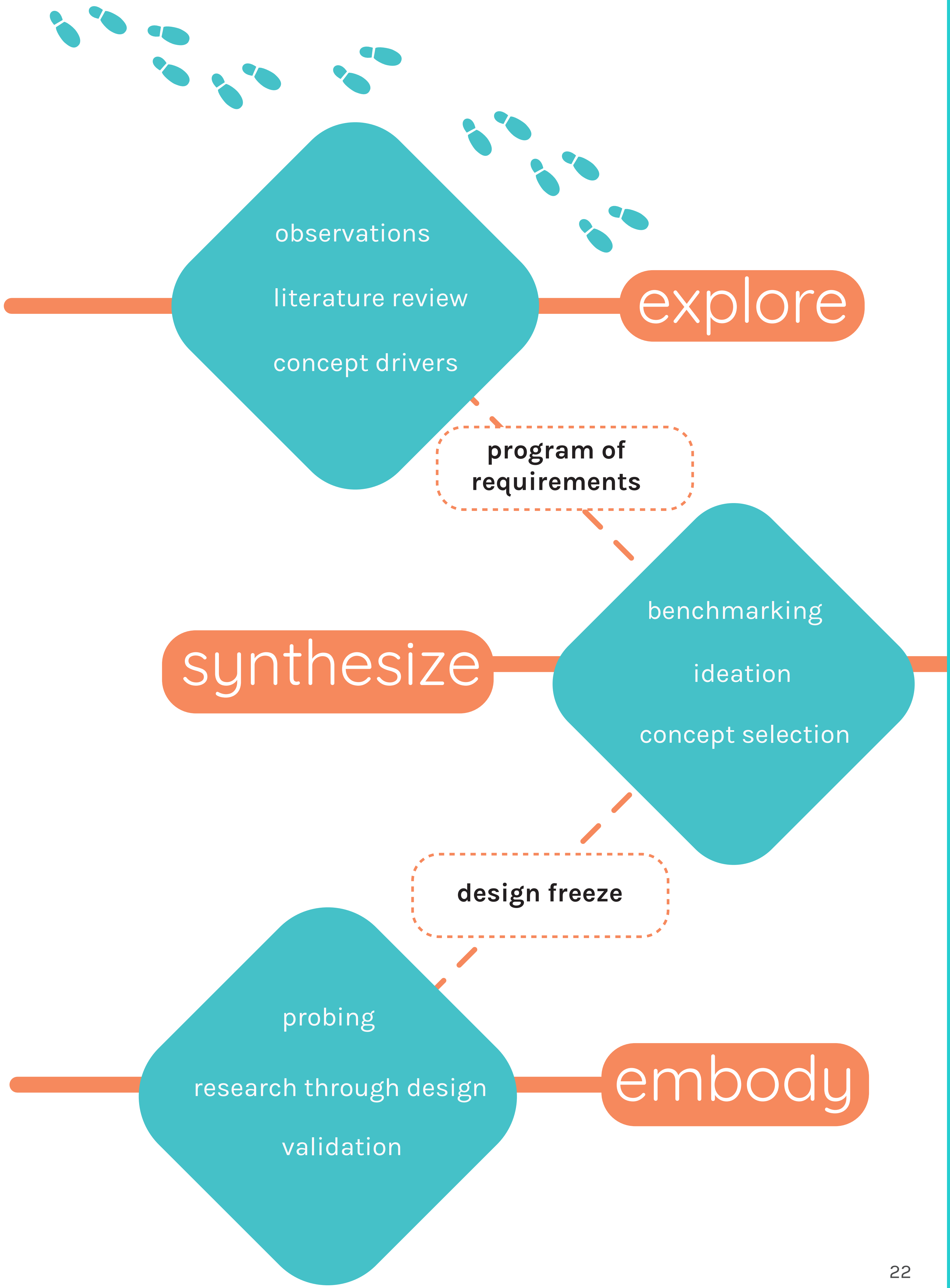
air bubble formation
ease of inflation for modular blocks
reducing frustration while connecting blocks
lego compatibility issues
integrating sensors into the modular blocks
casting process

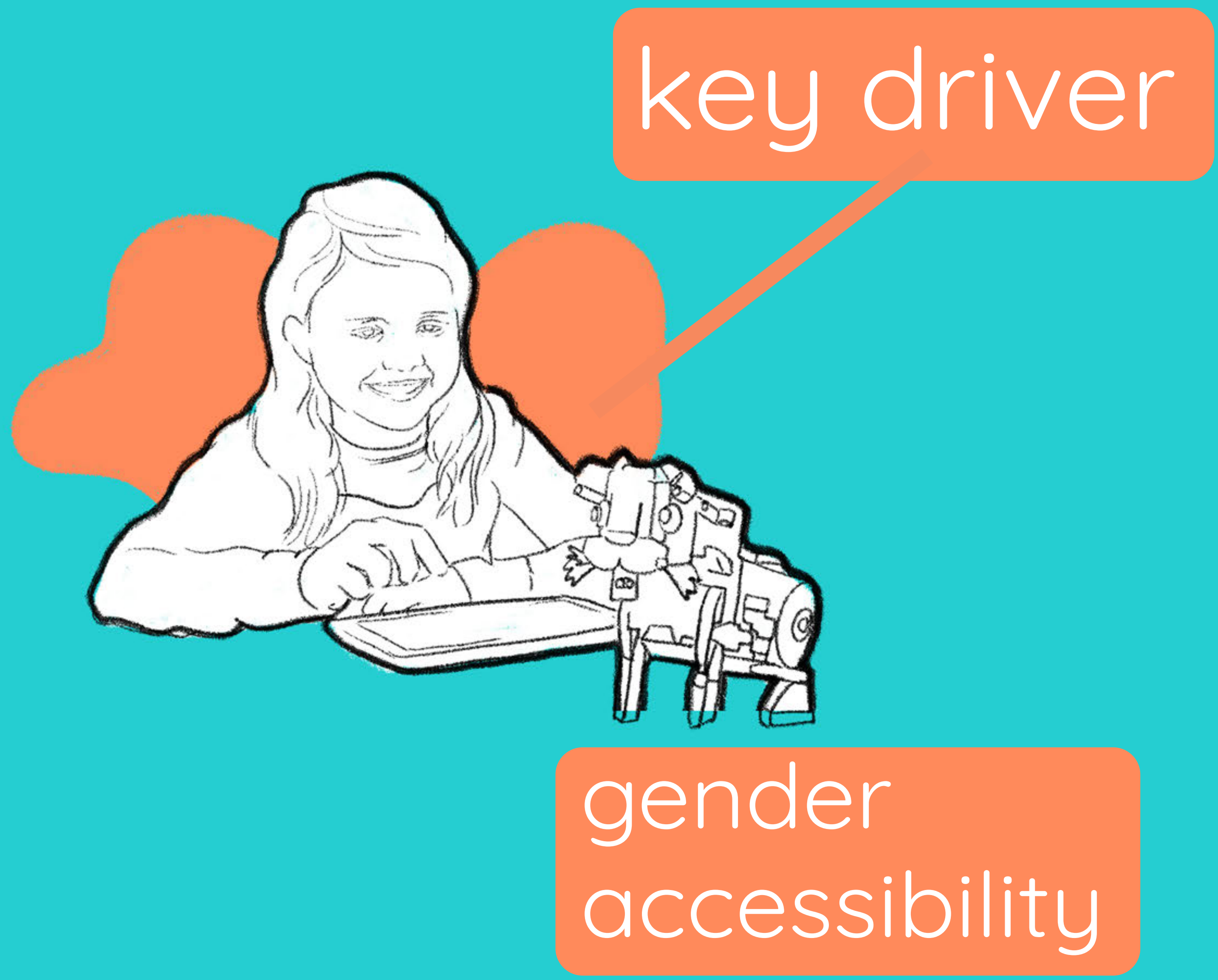
appendix E

miscellaneous

graduation project brief
reflection

explore


observations
literature review
concept drivers
explore
program of requirements
benchmarking
ideation
concept selection
synthesize
design freeze
probing
research through design
validation
embody


key driver
gender accessibility

1.1
gender divide in stem toys

One of the main reasons behind unemployment , income disparities and workplace discrimination against women can be majorly attributed to resource availability. (Ceci, 2011) Among these resources, the development of science and math skills in early childhood through the use of science and math geared toys are considered to be important. (Meece, 2006)

Toys could essentially be viewed as 'interest gathering instruments'. For instance, a teenager playing with a toy microscope could potentially spark an interest in the individual to examine microbes more closely, or help choose professions because of the interest buildup. What is however interesting is the disproportionate difference in the types of STEM toys both girls and boys play with.

These have been repeatedly confirmed by various studies which demarcate a significant difference along genderised lines both in terms of access and interest to these toys. (Jacob Inman, 2015) For instance, although several toys available in the market are 'gender-neutral' by design, they are not designed to be 'gender-accessible', which leads to an increased disparity in the type of toys both girls and boys play with.

R01

Making it gender-accessible revolves around a lot of factors. Right from the subjective preference of various toys, and the ways in which the toys are marketed by the companies and the way in which they are strategically placed in the toy stores, all these have an influence in terms of bringing forward the desired gender-accessibility.

The hot topic of research right now, with continued investigation has been to observe the gender denominator when it comes to subjective preference of the types of toys children play with. How much of it could be attributed to the 'nature' or the inherent sex, and how much of this could be attributed to 'nurture' or social conditioning?

R02

Taking the specific case of robotics, studies have been carried out for older age groups, where males outperform females in robotics and programming related fields, and it is essentially hypothesized that there might have been a cultural indoctrination in the overall effect which it has had on the students. (Sullivan and Bers, 2013)

Another aspect of research which is currently being investigated is in terms of how early the sense of gender and identity kicks in. Usually by the age of 24 months (Baumgarten, 2003), they begin to define themselves as 'boys' or 'girls'. (Freeman 2007) And in this way, they begin to construct and categorise 'girl toys' and 'boy toys' to behave as they think they 'should'. In this study, the 5 year olds sorted toys more stereotypically than the 3 year olds, showing the influence of social conditioning over the preference of toys.

From these studies, it has been observed that the toys largely purchased by boys are more oriented towards construction right from a very young age, while being typically overlooked for girls due to its lack of perceived benefit or enjoyment. These gender separations in engineering, constructions and robotics related toys could have a lingering effect of gender-biased toy purchasing at younger ages (i.e stacking objects for boys, dolls for girls) (Inman and Cardella, 2015)

representation of genders for science and math related toys

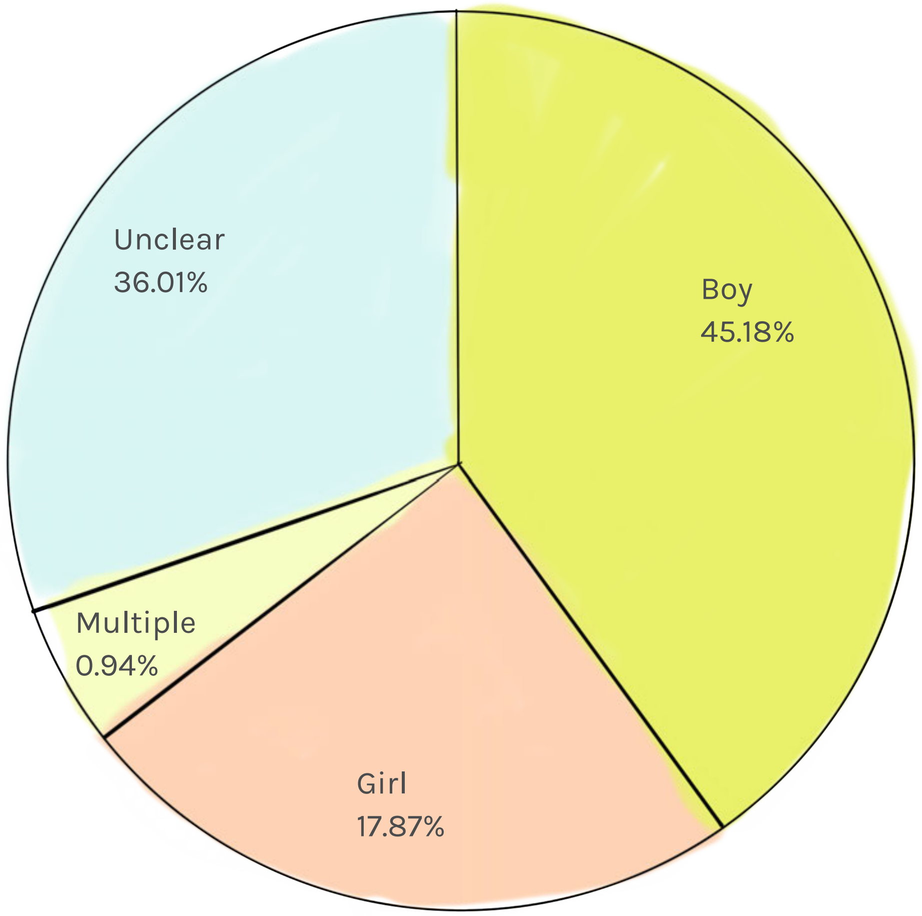
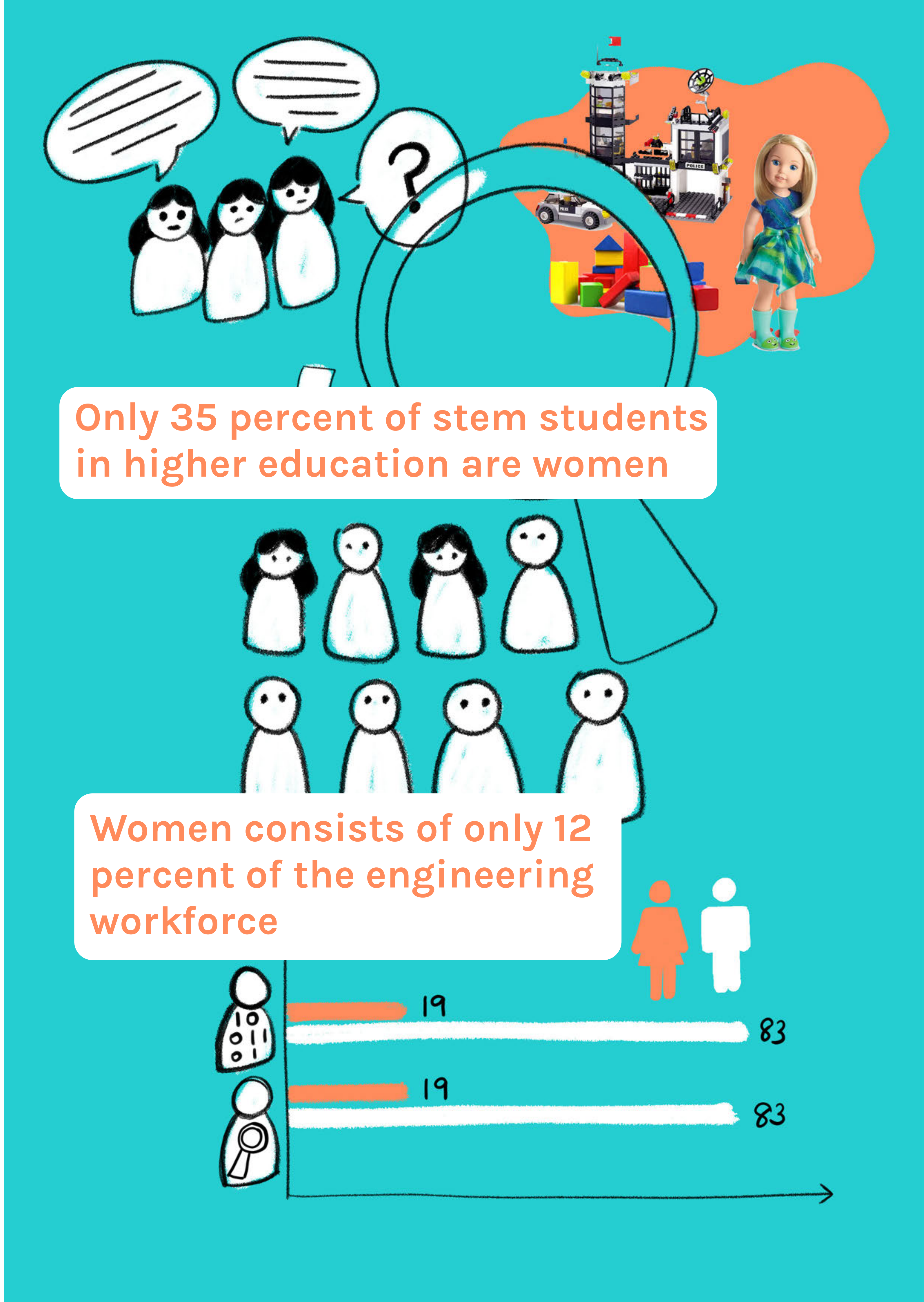


Fig. (1.1) Representation of reviews from Amazon and MindWare on specific math and science related toys (Jacob Inman, 2015)

R03 From these studies, it becomes more evident that the best way to tackle the issue of gender accessibility would be to include the best of both worlds - of both roleplay (indicated by the likeability to dolls for girls) and constructive play (indicated by the interest towards building blocks and stacking objects) to balance the equation systemically.



1.1.2
where does this gender bias stem from?

There are multiple theories associated with the reasons behind it such as gendered socialisation, peer group nature, or even the general stereotypes of STEM professionals which leads to this nature.

Summarising all these insights which look into the effects on gender in terms of toy selection, preference and future professions which the children take up, it becomes clear that it is very much important to decouple ‘masculinity’ from STEM fields, to reduce the divide. The narrow construction of gender limit opportunities along genderised lines when it comes to play based approaches for play based learning which involves robotics and programming.

The gender constructions might lead to specific disadvantaged situations for girls in traditionally masculine areas. And this is heavily influenced by the stereotype threat which explains as one of the main reasons behind this issue. A study on how women experience math was carried out (Spencer et. al 1998) wherein women were shown gender differences on a math test before being asked to complete it, and they performed significantly worse than their counterparts. Through such cases, it is shown that stereotype threat could be triggered by explicit statements apart from environmental and situational factors. Reducing stereotype threat is an important challenge that both parents and educators face.

R04

One such approach to reduce this bias is by making educational robotics toys accessible for children of both the genders at a very young age before stereotypical biases kicks in. (Sullivan and Bers 2013) This could be fundamental as gender based toy play could lead to differences in the cognitive and social skills of boys and girls. And addressing this issue could in effect, lead to an increased adoption of STEM based jobs for women and bring in more diversity to these fields.

scope

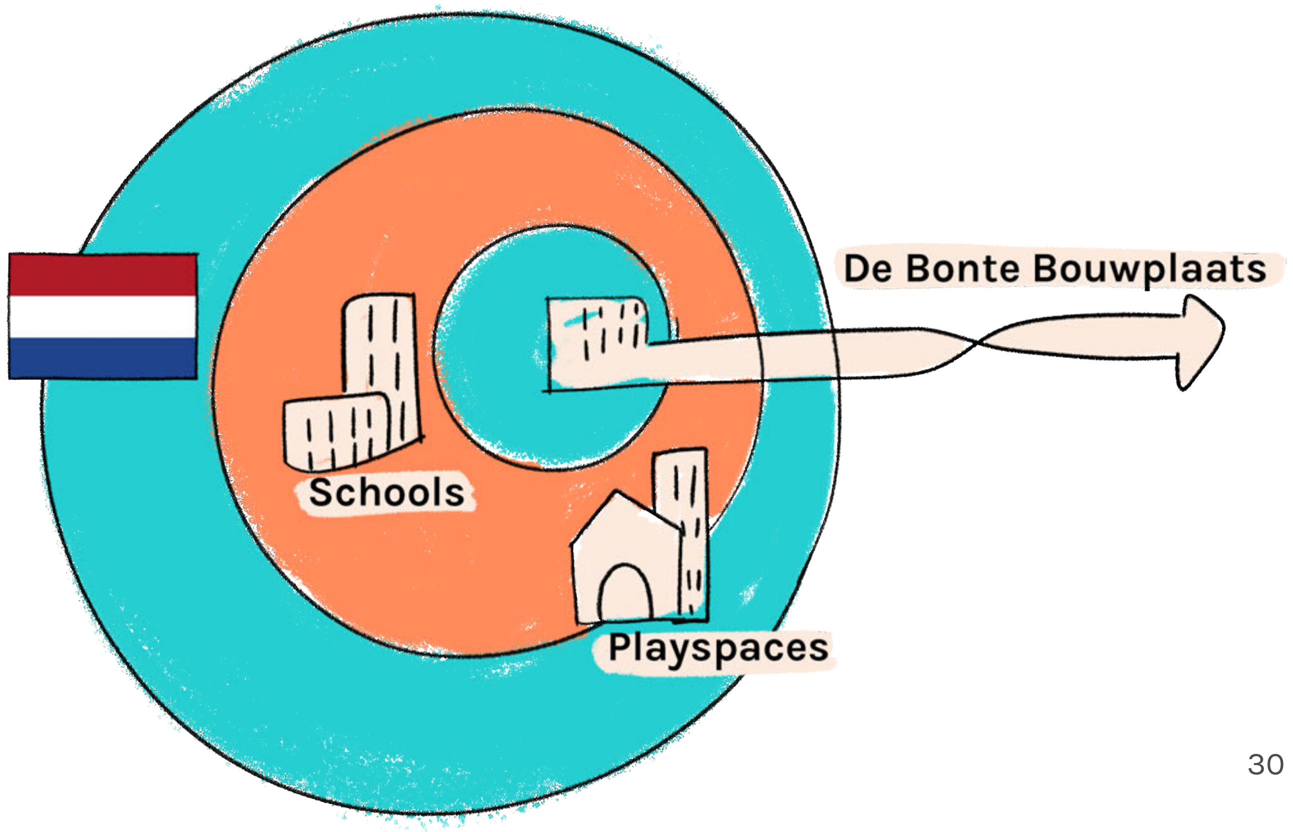
1.2.1

The scope of this graduation thesis is focussed towards addressing the gender accessibility issue with respect to STEM education through play. In the initial phase, research on various kinds of play is carried out to understand the focus group of preschoolers (4-7 year olds) better.

For the user group exploration, the LEGO playspaces are taken as the focal point of the thesis. Within the playspace, the interactions of children who visit, the toys they usually play with, and their interests are studied in a more closer sense to identify viable opportunities for intervention.

The thesis also revolves around the specific technology exploration of soft robots. With this being an upcoming and diverse field with multifarious applications, the scope is defined around coming up with specific applications of soft actuators particularly in the domain of robotics education for the preschoolers. Under soft robotics, various inflatable actuators would be investigated to arrive at a desired embodiment that fits the context and the user group. Inflation is pre-defined to be a key part in the future concept exploration phase as well as shown in (Chapter 2.5)

To make both ends meet, that of addressing gender accessibility and also accomodating the open ended applications of soft robotics, the technicalities and potentialities are charted and mapped out to find the relevant intersections that would help in detailing the thesis.



context

1.2.2

LEGO Playspaces act as a gateway for younger children who are fascinated by all things LEGO. As there are a wide variety of learning outcomes through such playspaces in terms of robotics, programming etc, It acts as a hubspot to engage children in meaningful ways.

With this being a conducive medium for learning through play, this was chosen as the appropriate context to investigate what interests kids of the age group between 4 to 7 particularly along the lines of robotics and programming.

De Bonte Bouwplaats in Delft, Netherlands, one of the many LEGO playspaces located in the Netherlands was chosen as the primary place of observation,

Through the wide variety of LEGO kits made available for different age groups such as WeDo, Mindstorms, Boost and so on, the kids involve in various STEM related challenges using these toys.

However, despite the success of these toys, there are certain limitations with respect to the pricing of these kits. Despite their very user-friendly interfaces, these individual kits are usually expensive ranging (eg. $280 for a LEGO Mindstorms NXT 2.0 set) (Finio et al 2013) Therefore, the parents find it more convenient to give children access to these playspaces which have a wide variety of LEGO based kits to choose from. However, not all children have access to such LEGO playspaces as they are not sufficient, even in the Netherlands.

R05

Although LEGO playspaces are chosen as the context for this thesis, the research work could extend beyond LEGO playspaces and into schools and even libraries. These LEGO playspaces therefore act as a launchpad for understanding how novel methods of play based learning could fit into the existing LEGO universe.

Figure (1.1) A glimpse of one of the LEGO parties conducted by de Bonte Bouwplaats

stakeholders

1.3

This project is encompassive of the research interest from Applied Labs of IDE Faculty and De Bonte Bouwplaats (LEGO Playspace). The thesis would be focussed on tackling the gender accessibility for robotics education by arriving at a new way of play by means of inflatables.

As the target user group are the children between the age group of 4 to 7 years of age, with the primary economic buyer being the parents who influence the decision to buy the product. R06

Libraries, makerspaces and schools would also be influential at a later stage owing to the educative component of this toy.

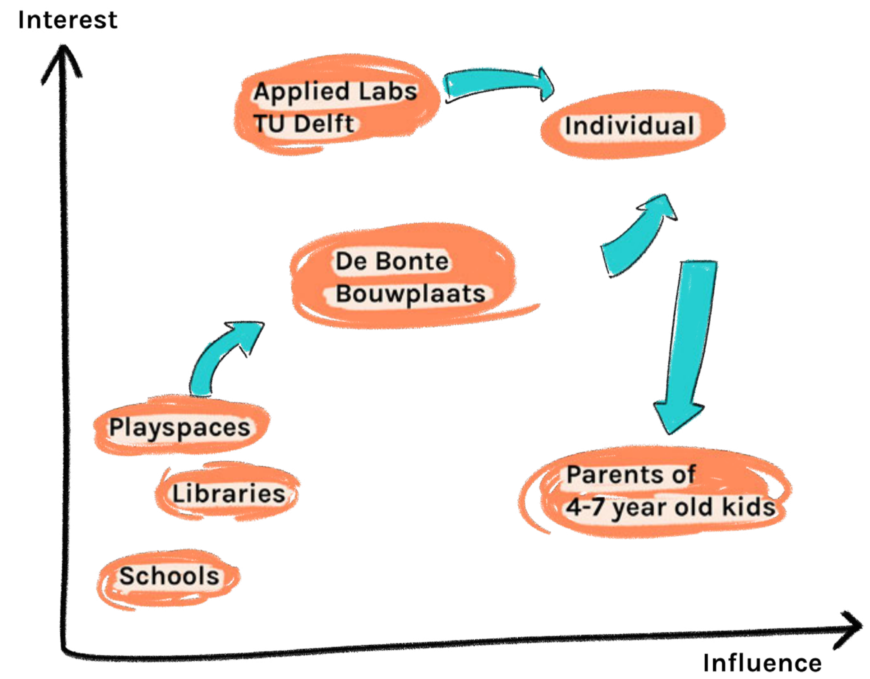


Fig. (1.2) Stakeholder map of interest versus influence

why dutch audience?

Netherlands has the fastest growing toy market in Western Europe which showed a growth of 3 percent in 2017. STEM related toys are especially trending in UK, Finland, Australia, Canada and the Netherlands.

1.4

Personas

Name Tjak
Age 7
Likes to play with LEGO
Dreams about characters and superheroes to play with
Favourite LEGO set: LEGO Star

Name Ellen
LEGO Play instructor
Likes all things LEGO
Observed educator for more than 20 years
Enjoys organising LEGO Birthday parties

Name Anna
Age 7
Enjoys drama and storytelling
Favourite LEGO set: LEGO Friends

1.5

why soft robotics?

The Foundational Labs at the Faculty of Industrial Design, TU Delft has been involved with respect to research on soft robotics. The main research focus is with respect to the sensing, modelling and structural optimization for soft material robots. At present, robots that assist in elderly care, soft orthoses and intelligent soft robotic products such as seats and mattresses are currently being explored.

One of the main reasons behind the usage of soft robotics is in its provision of an exciting trajectory in the field of human-robot interaction. It is becoming increasingly possible to make robots that are adaptive, flexible and resilient owing to the advancements in this field.

In this case of exploring play based learning, an exploration of soft robotics is predefined in the very scope of the project owing to the following reasons:

Robotics in education
Teaching robotics provides value in terms of social and provides well rounded integration of various subjects in a holistic way, R07
while improving social skills along the way. (Johnson, J. (2003))

Versatile use cases
As we imagine closer human-robot interaction, the softness and versatility would bring in a lot more possibilities for our future. R08
Helping younger children understand the basics of this field could inspire them in the future to develop robots, both hard and soft. (Majidi, C. (2014))

Tactile Interaction
Added advantage in terms of product experience (Arnold, T., & Scheutz, M. (2017)) Products such as Paro have already shown how the soft, plush surfaces have therapeutic value for elder R09
companionship

Breaking free from stereotypes
As the current notions of who should interact (or) what should be interacted with are self-limiting especially for children at a young age, the new domain of soft robotics provides scope for creating a new language of expression of what a 'robot' means as shown in Fig. (1.3)

what comes to your mind when someone utters the word ‘robot’?

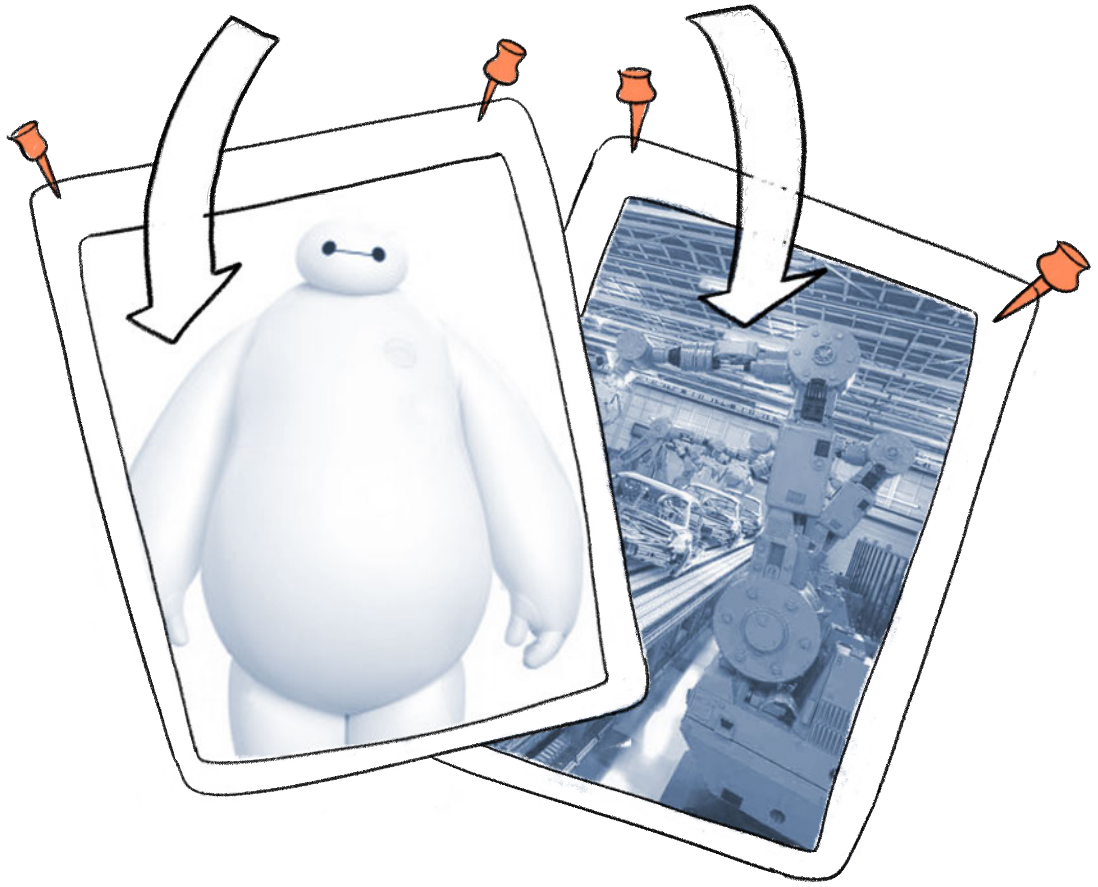


Figure (1.3) Usually the mental model, or the image which comes to a persons mind when someone utters the word ‘robot’ is usually the hard metallic machines which science fiction promised us. Contrasting to this image, robots could also be rubber like and felxible in nature.

research outline

1.6

The initial research process was based on formulating the required vision for the thesis. To aid this process, literature studies and primary observations were conducted at the research context (De Bonte Bouwplaats). Apart from this, the learning methodologies and types of play for younger children were also investigated to formulate design guidelines. Personas of the key stakeholders related to this project were also carried out. In the end, there was synthesis of all these various fronts giving rise to four main drivers crucial to the vision.

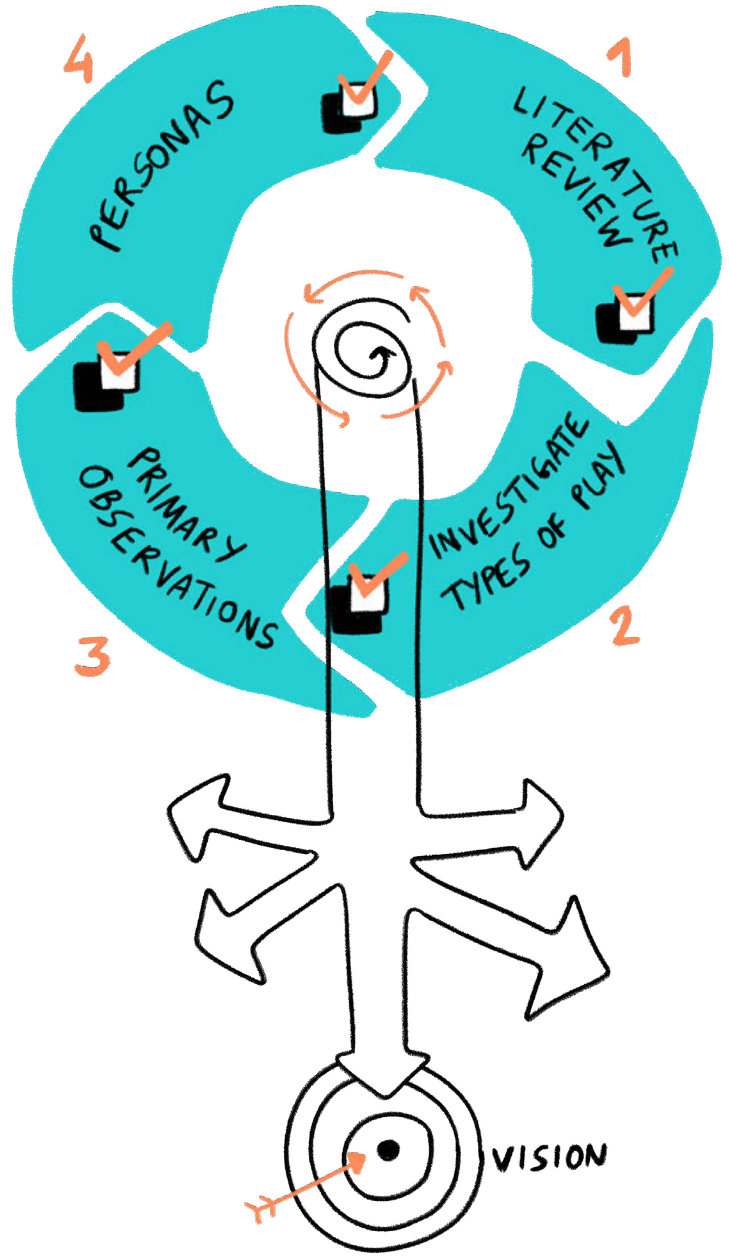
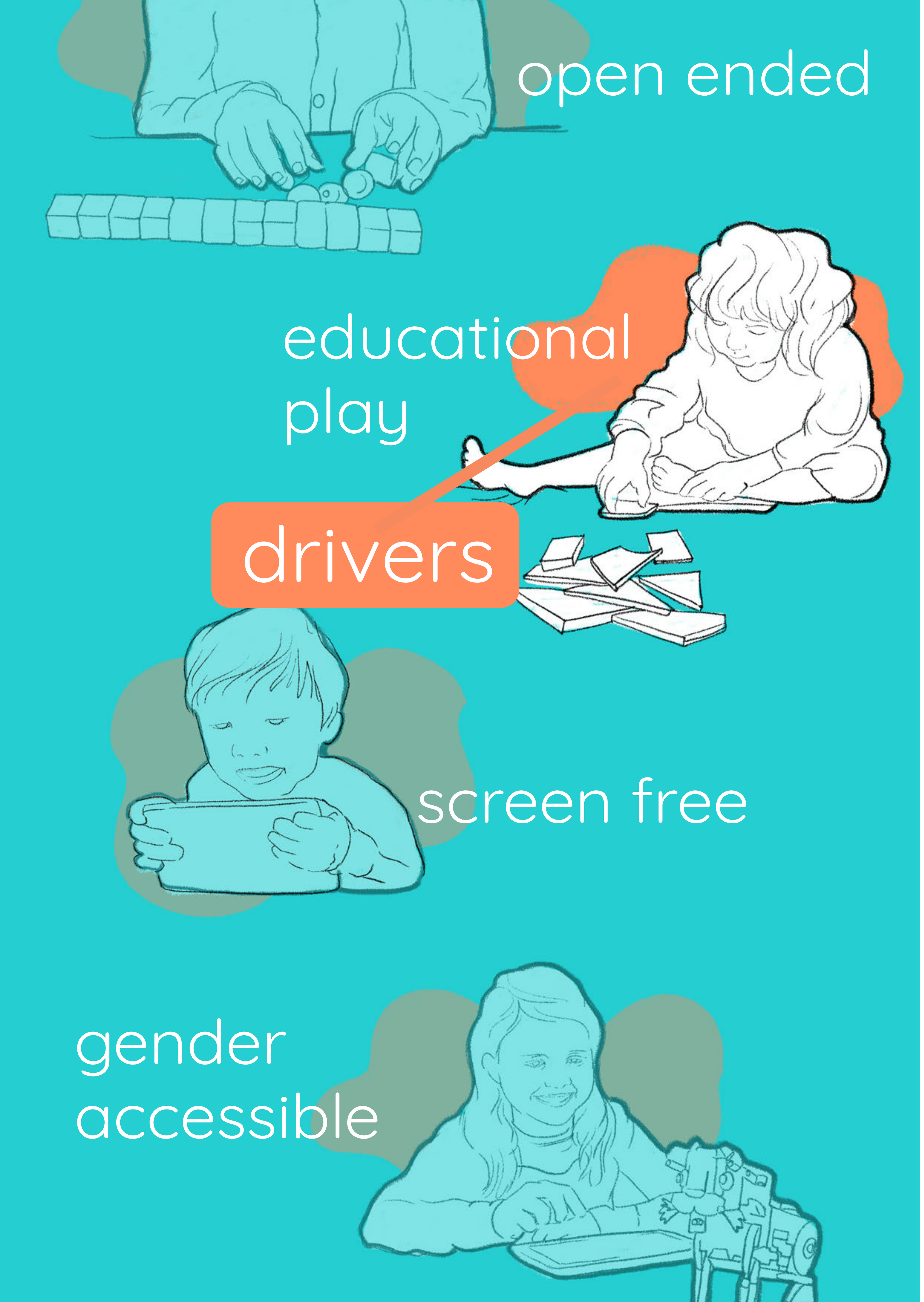


Fig. 1.4 Outline of the research navigation workflow to arrive at the vision



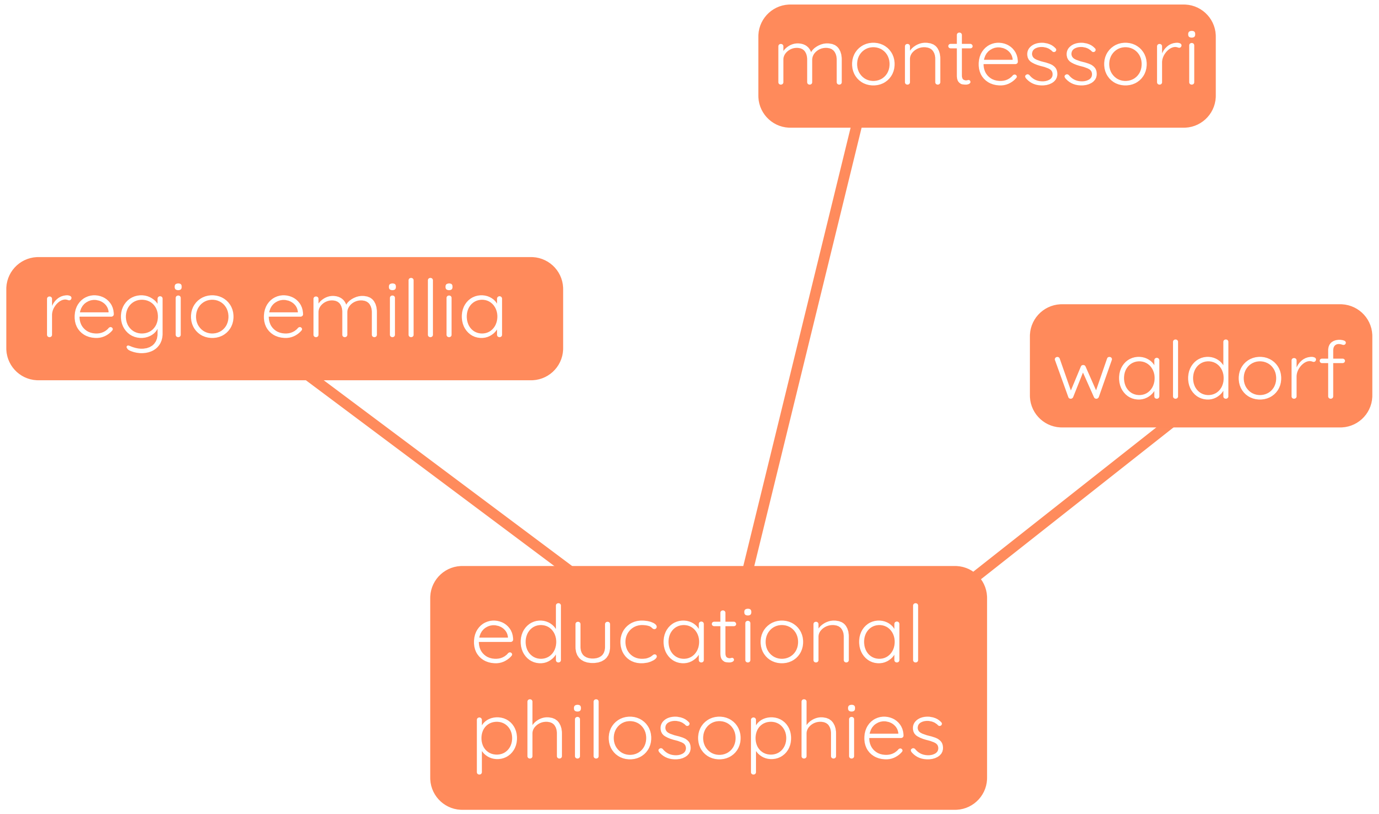
educational play

1.7
how do children learn?

To decipher how there could be effective ways of providing learning through play, it becomes increasingly important to understand learning through first principles. How do children learn? And what are the current practices through which they learn?

To understand the pedagogy of children from this age group better, the most commonly applied philosophies of education for this age group were investigated. Especially in Europe, the Regilio Emillia, Waldorf and Montessori methods of education which are very much child-centered as compared to the traditional instructive mode of teacher-student relationship. (Edwards and Carolyn Pope, 2002)

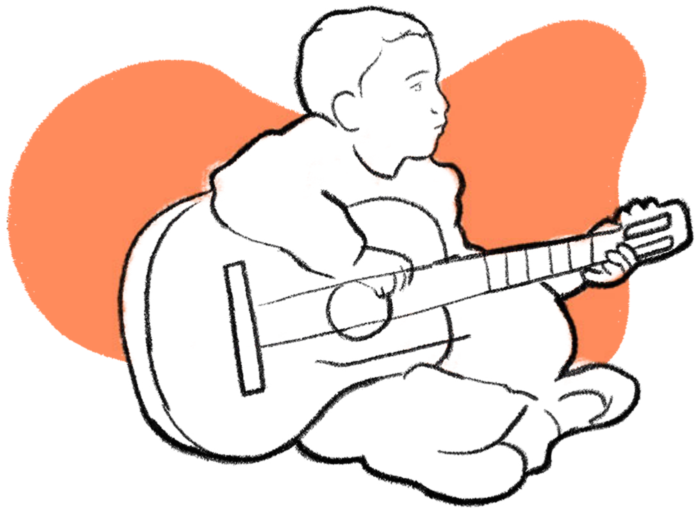
The investigation of these three schools provides a perspective on how to best involve in educative play of children of the concerned age group from 4 to 7 years.



1.7.2
montessori

This is one of the most popular schools of thought, with a strong emphasis on child centered education with teachers serving more of facilitators.

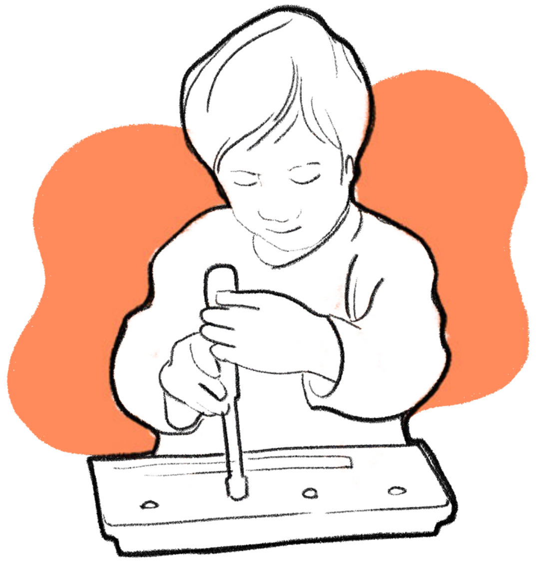
R10 The central theme is that 'children learn at their own pace'. Mixed age groups are encouraged in this environment, with older children serving as role models for younger children. In terms of toys, there are special Montessori toys which are used, also called as 'manipulatives' which are self corrective in nature.



> **I hear, I forget**
> **I see, I remember**
> **I experience, I understand**

1.7.3
regio emillia

R11 In this school, children are prompted to explore topics and interests on their own and it is very much child-focussed and teacher-framed. As they explore topics of interest through storytelling, toys and other media, they understand psychological causality in stories and realise that characters have goals and beliefs that may otherwise influence their behaviour. (Gelderblom, 2008) If that's the case, the meaning and purpose behind the toy i.e the story behind the toy becomes equally important. If the children can see the point in solving a problem, they are likely to remain engaged.



This approach values which values the child as strong, capable and resilient; rich with wonder and knowledge. This also involves adequate documentation of the work which children do in the form of photos, videos and other materials. (Gergich, 2020)

environment as educator

Developing an environment conducive to help children gain sensorial impressions

child centered

Project based curriculum with lessons based on childrens interests

documentation

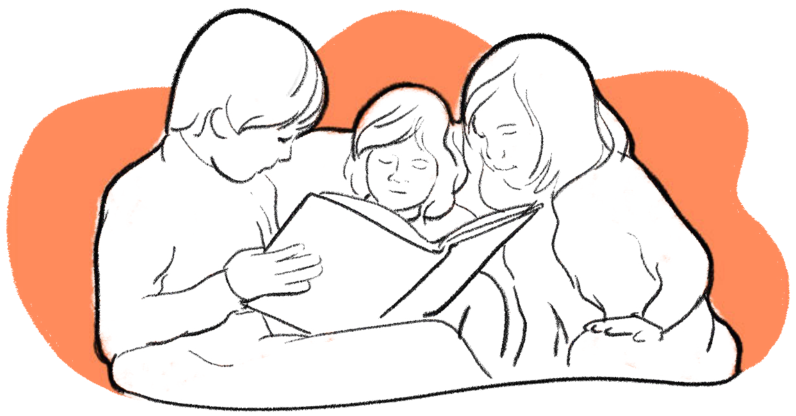
Documenting what kids do in the form of photos, videos and so on.

1.7.4

waldorf

R12 It is based on the philosophy of anthroposophy, the belief that one's own spiritual development, has the wisdom to transform itself and the world. There is a lot of outdoor-based activities which are encouraged and a routine of play-based activities are followed. (Ghergich, 2020)

For example, gardening on Mondays, Baking on Tuesdays and so on. Usage of media and electronics of any form are not encouraged during school hours. It is mostly encouraged by parents who want their children to have a cooperative, creative, routine based setting.



"

Where is the book in which the teacher can read about what teaching is? The children themselves are this book.

types of play

1.8

Having explored various ways in which children learn, it comes to a question as to understand how this age group of interest (4-7 years old) play.

In this context, three primary types of play such as building play, explorative play and role play are investigated to understand the key aspects of each.

Addition to this, recent science and math based toys, especially the ones geared towards robotics are investigated to understand were they fit into this landscape.

how do children play?

building play

R13 Basic manipulatives in the form of building blocks are added and subtracted in various combinations in building play.

In this age group of 4 to 7, simple geometric forms are explored where loose blocks are combined with other blocks (mostly with a minimum of 3.5 inch square having 1.5 inch thickness) Children of this age group also engage in a wide variety of arm, hand and body coordination during play and are not constrained by it.

explorative play

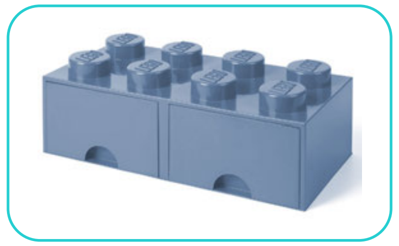
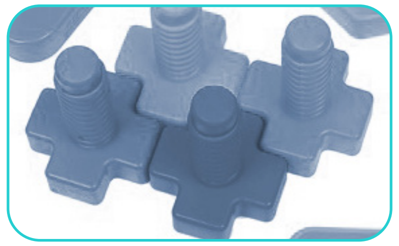
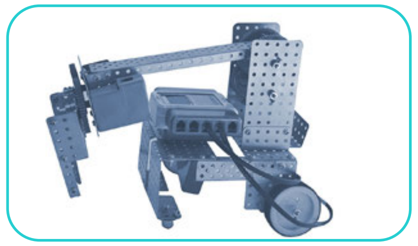
R13 Moderate cause and effect functionality is explored (such as pushing buttons producing lights and so on) This play is mostly explorative and trial and error based requiring a finite amount of hand dexterity.

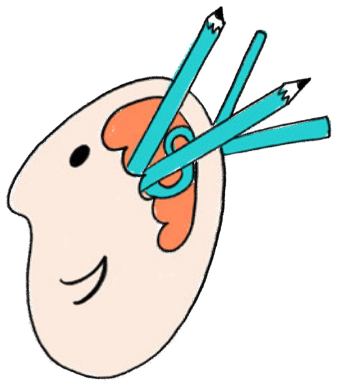
The children of this age group find interlocking play much more interesting and for the older age groups of 7 to 8, they can work with motorised robotic blocks which can have certain cause and effect relationships. Smaller fixtures such as nuts and bolts are usually avoided, unless they are made 2-3 inches larger.

role play

Role play is mostly comprised of enacting and re-enacting stories. R15 There could be dress up themes revolving around fire, dinosaurs, pets, spaceships etc. They also do enjoy roleplaying with costumes, accessories and other kits.

LEGO through its kits also involves children in theme based construction such as the making of Star Wars, Ice Cream Trucks, Empire State bulding and so on.

Age	4-5	6-8
Building Play	Bigger blocks for play (~3.5 inch into 1.5 inch) 	Along with these building blocks, dramatic storylines are added 
Explorative Play	moderate degree of finite motor dexterity and control, vibrant pastel colors used 	moderate degree of finite motor dexterity and control used
Interlocking Building Materials	Consists of large nuts and bolts in larger sizing. 	Can work with robotic blocks, highly enjoy theme based kits 
Role Play	Dress-up themes, re-enacting stories 	Enjoying more detailed costumers (superheroes, accessories etc) (Melissa, 2020) 



1.8.2
how do children think?

Although the previous categories of types of play and types of learning sheds some insight on the psychology of the child approaching or passing through this age group, there has been an investigation into the child's thought process by Piaget, Gelderblom and others.

One of the main insights from these child psychologists has been on how a child's thinking becomes more and more operational i.e the innate ability to reverse any operation mentally. For instance, a child of three can put objects in a row, move them around and move them back; a child of seven can do the same in a mental space. These insights become important guidelines while designing technology for children to learn and interact with.

R16

Therefore, the product should be possible for the child to fit the information presented into existing schemes (assimilation), adapt existing schemes so that the new information can find a place (accommodation), or combine existing schemes to form more complex schemes (organisation).

R17

In addition to that, to support the reversibility skills which become gradually better with the progression of age, activities that include reverse actions such as combining, ordering, separating and recombining of elements becomes particularly important. (Gelderblom, 2008) This, in a way, explains the grounding philosophy of constructivism and how it is very essential for the child's development and the subsequent success of combinatory toys such as LEGO, K'nex and so on.

1.8.3
how does robotics help children learn?

How does robotics enable children to learn? How does robotics differ from other ways of supported learning? What is special about this medium?

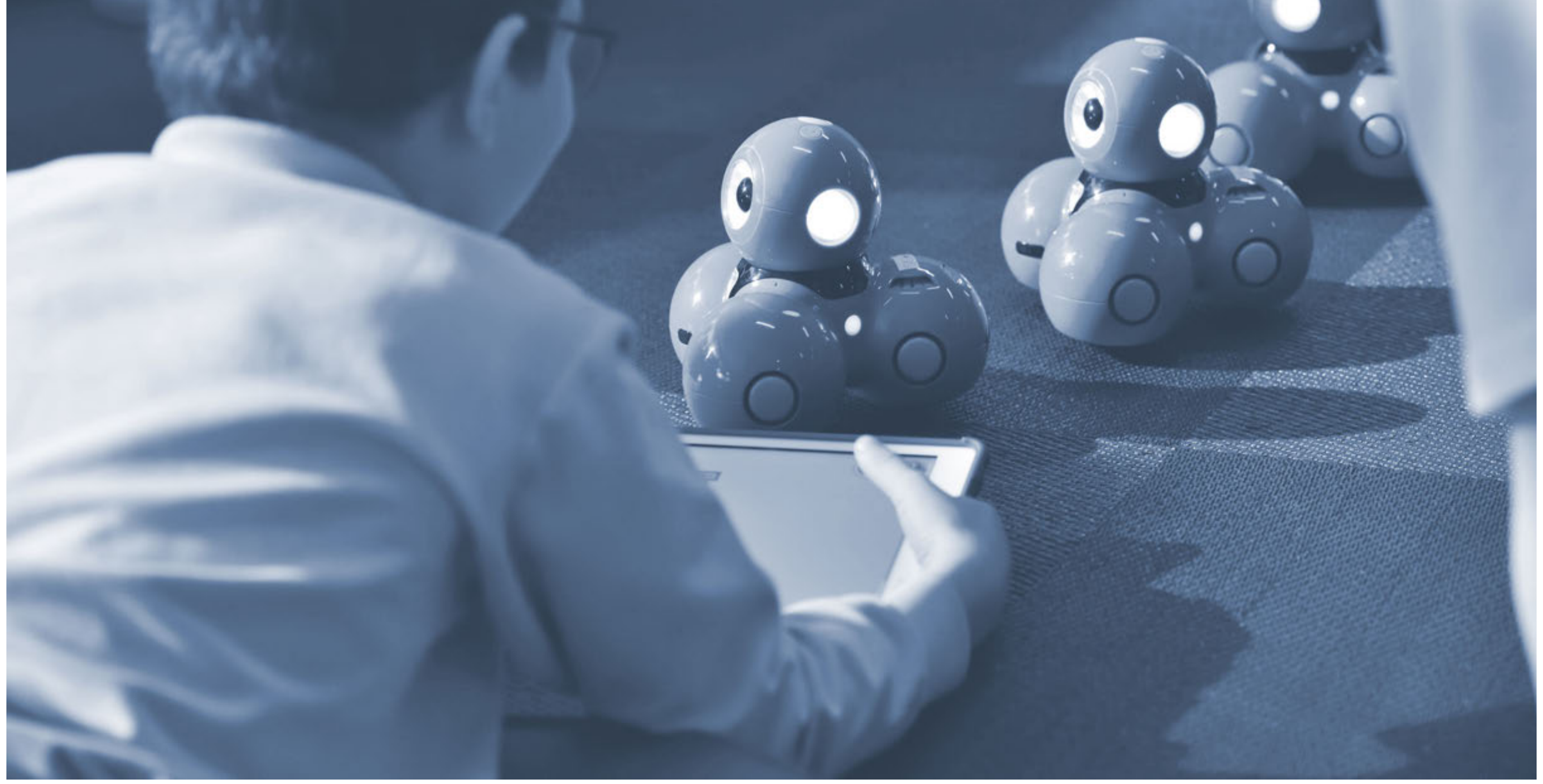
Part of the answer lies in how robotics is very multi-faceted in combining various disciplines such as science, technology, engineering and mathematics. For example, with respect to imbibing various themes such as Algebra and trigonometry, Design and innovation, Electronics and programming, Forces and laws of motion, Materials and physical processes (Johnson 2003)

There is a combined synthesis of various different things which makes learning robotics particularly enriching for younger kids. Apart from helping students learn standards-aligned science and math content which are the 'hard' skills that they learn. Apart from this, they also learn essential soft skills such as collaboration, critical thinking and problem solving. (Johnson, 2003)

If this were the case, coming back to our rationale of how gender accessibility could be brought about especially for science and math toys (which includes robotics based toys as well). it would be a severe disadvantage if this medium is made attractive just to boys. According to Lund and Pagliarini, this would be a severe blow for girls in terms of the edutainment aspirations, and girls will indeed have to engage in robot activities. Instead of merely pushing them into this domain, thoughtful design should nudge and provoke an interest among girls as well towards such edutainment aspirations.

R18

Surprisingly, even learning robotics is riddled by conventional male cliches such as speed, power, competition and destruction and there is a need to move beyong these notions, which might pose as a major challenge for educators or even toy designers for that matter.



1.8.4
how do STEM toys make a difference?

With the recent advent of STEM toys which place an equal emphasis on learning, Montessori, Waldorf and Regio Emillia have become marketable catch-phrases as observed in various crowdfunding websites popular for the sale of STEM toys (Kickstarter etc) These toys help children learn advanced concepts such as robotics, programming in a simple and intuitive manner.

Especially for robotics education, there have been countless demonstrations and workshops indicating how this could have a more meaningful impact on the development of the child as mentioned in (Yu. et. al 2013)

And as a result, teachers and educators looking to impart the less tangible outcomes such as communicating the joy of learning, fascination towards subjects etc are driven towards robotics education at a younger age for
R19 children. This movement is also evolving as a natural response by the parents who would like to take action against the traditional curricula that dont offer the children the content and pedagogy required for active problem solving.

The major distinctions are examined as to how it is different from the other conventional ways of learning, or what is special about the medium? Some argue that it is being used to teach Science and Maths concepts and if it is in fact more effective than the current platforms. Owing to the way in which various disciplines are synthesized through this medium. (Johnson 2003)

1.8.5
in sum

To understand the aspect of 'educational play' or in other words, 'learning through play', several aspects of understanding this term was touched upon ranging from how do children learn? How do they play? And how do they think? From this analysis, the whole advent of STEM toys, and robotics toys were touched upon to understand how they provide holistic education of the children also making sure that it is engaging and much more fun to play with.

The holistic view of education is quite contrarian when compared to the mainstream educational system. The LEGO Foundation takes a similar approach of holistic view of learning which comprises of cognitive, social, emotional, creative and physical. (Parker and Thomson, 2019) This redefinition of play based learning provides an important foundation to evaluate the design of the product.

1.8.6

The eight pedagogical principles are as follows -

R20 **Active Learning**
Defines the cognitive, emotional and behavioural activity for better student engagement

R21 **Co-operative and Collaborative learning**
Approaches designed to maximise positive peer interactions through thoughtfully structured group

R22 **Experiential learning**
Notion that quality experiences within and beyond the classroom promote meaningful learning

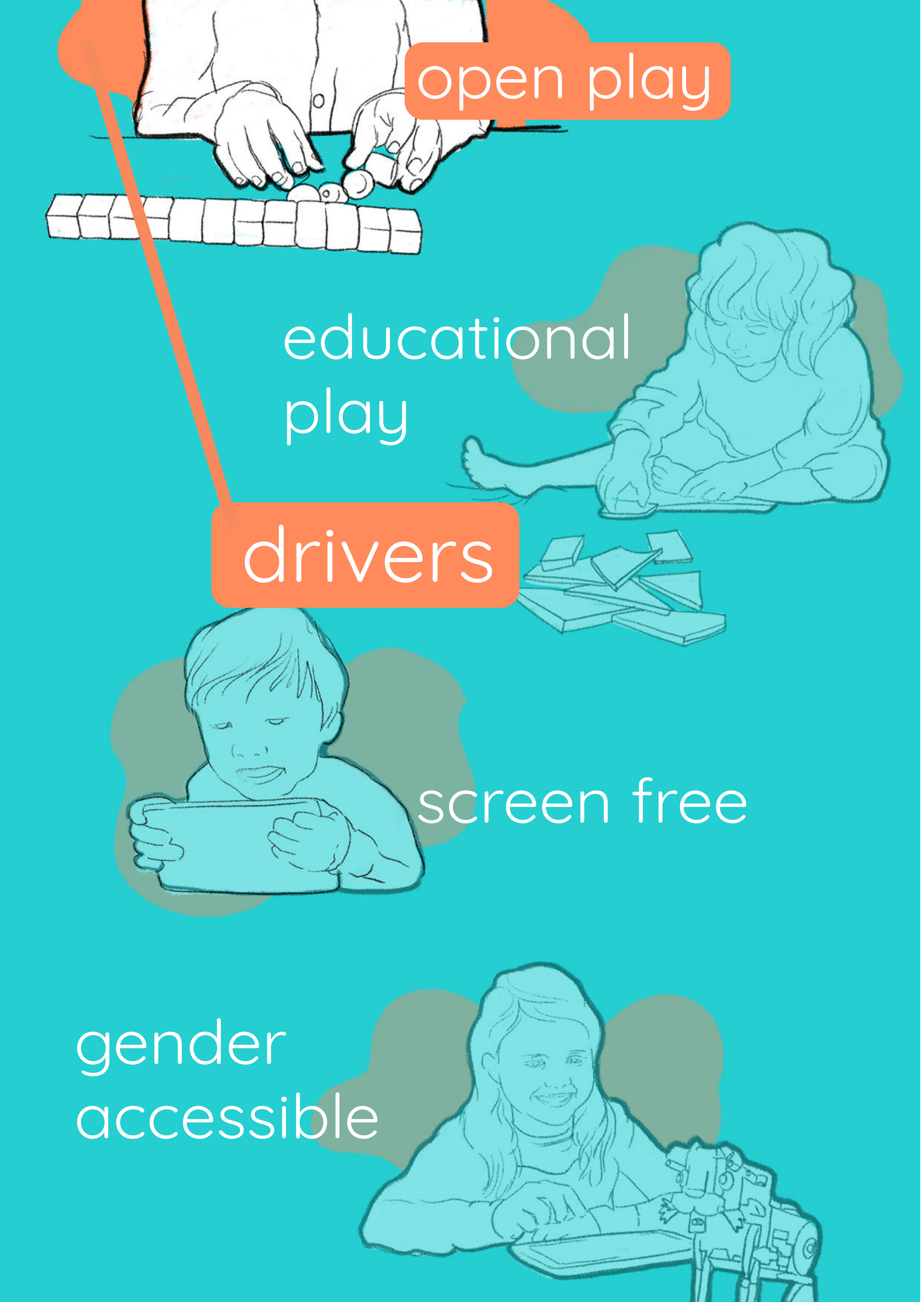
R23 **Guided discovery learning**
to be expected ' to expect and be prepared to discover knowledge' with the support and scaffolding of a teacher

R24 **Inquiry based learning**
Involves organising a unit of work around relevant authentic, open-ended questions

R25 **Problem based learning**
Involves structuring an integrative learning unit around a problem. The richness of the vehicle acts as a problem.

R26 **Project based learning**
Projects as vehicle for delivering the curricula.

Montessori education
Characterised by hands on education by group and hands-on work, self directed learning with teacher guidance, with a lack of competition and extrinsic rewards or punishments



open play

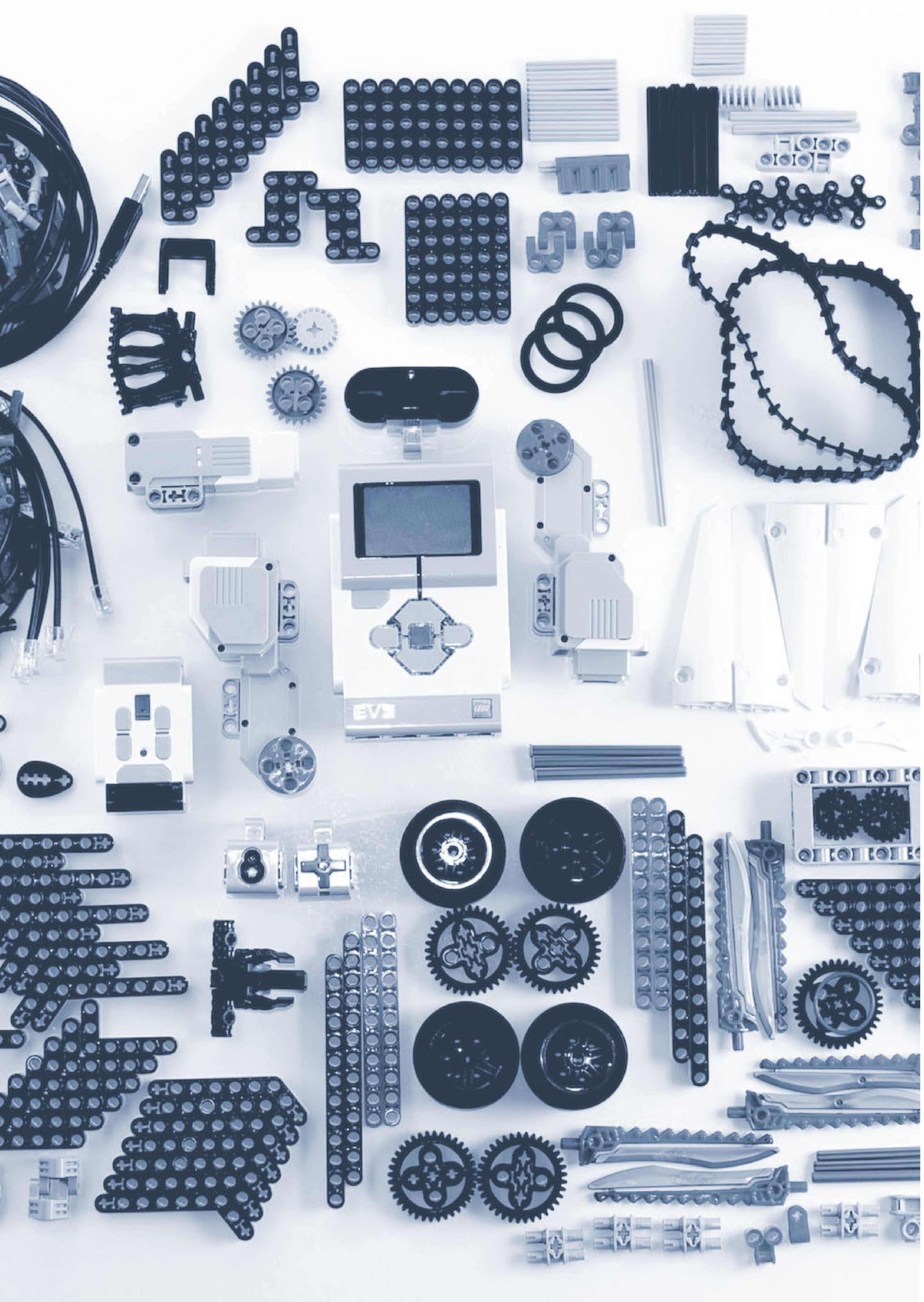
1.9

Over the past few decades, there has been a paradigm shift from 'black box' preprogrammed and pre-fabricated robot, to a more 'white box' model in which users can construct an object themselves. Some of the major players leading this movement are LEGO, K'Nex and so on. LEGO has been providing educational solutions for primary school students engaging them in hands-on experiences to explore core STEM concepts.

The primary theory of educational robots which LEGO designs revolves around is the concept of constructivism, hugely influenced by Seymour Papert's influential paper on 'learning through doing'. The paper implied that children construct their own knowledge through activities in project based learning or by creating tangible objects. (Seong et. al 2020) Based on this philosophy of constructivism, there were a wide variety of toys introduced into the LEGO ecosystem. There have also been a surge in LEGO-Compatible toys in the market such as Brik-Tiles, InflatiBits and so on which add in to the existing ecosystem.

Constructivism, the philosophy of LEGO gives focus on open ended, tangible forms of expression where the children 'construct' their knowledge based on their own experiences. This also fit well with
R27 Regio Emilia, Waldorf and Montessori schools of thought which recognise how objects of play could aid in improving creative expressions.

For the 5 to 8 age group, children get initiated into the domain of robotics and programming through LEGO WeDo, Boost and Spike Prime series. The technical level and complexity increases with the age group, as LEGO Mindstorms provides added functionality as a programmable robot for 10+ year old children. Even in spite of all the features which these kits offer, they have been designed in such a way that it is easy to control them. (Seong et. al 2020)



Apart from catering to the educational demands as mentioned in the previous chapter, the product should also possess qualities of open ended play, providing more versatility and helping them exercise their creative potential in a better way. According to Paiget's three stages of development, the second stage (the preoperational stage) indicates that children develop
R28 their imagination and memory from ages three to seven which again becomes crucial as this age group is the focal point of this research.

Another key aspect of open ended play is that children have the ability to play without any instruction, in the sense that there is no
R29 'right or wrong' way to engage. There should be multiple ways for children to create and express.

In a way, because of the open ended and loose nature of parts, they could be constructed, manipulated and transformed through self-directed play.

R30 Another key advantage of open-ended play is in providing supportive scaffolding. i.e for children to maintain motivation and persistence, they should have an opportunity to successfully negotiate learning tasks. In other words, if they repeatedly fail they might lose interest, and in order to make sure that they learn optimally without losing interest owing to repeated failure, there should be challenging tasks just within their reach to help them move to their next understanding or skill. (Gelderblom, 2008)

The use of manipulatives such as LEGO, K'nex and other modular toys for supportive scaffolding is also better explained by Mihaly Csikszentmihalyi's theory of flow which illustrates the right tradeoff between difficulty level and engagement level for children.
R31 (Csikszentmihalyi, Mihaly (1990) Manipulatives which are based on modular blocks provide a set of primitives which reduce the frustration levels while beginning to play, but also ensures that they could progress on the learning front.

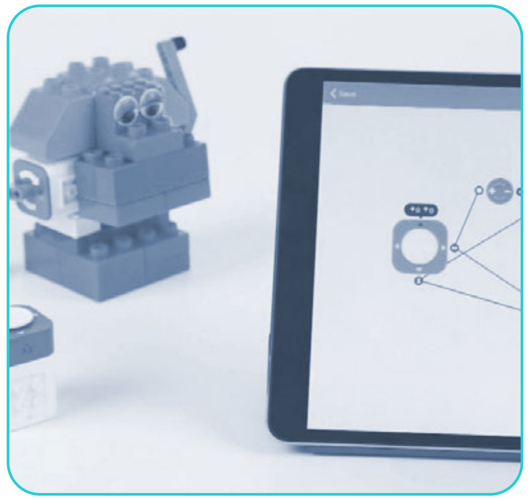
1.9.2
LEGO Compatibility

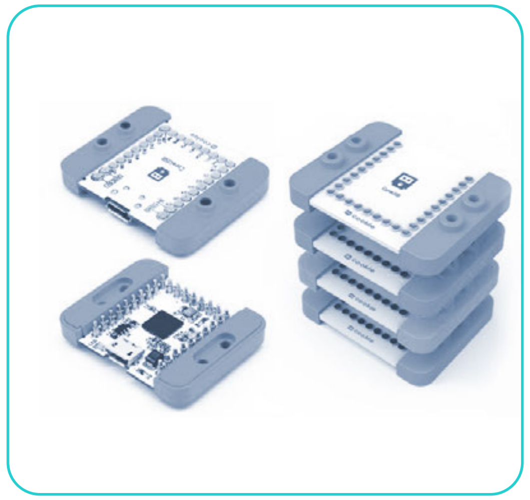
LEGO is undoubtedly the world's favourite toy. Right from various set themes to robotic themes all built around the educational theory of constructivism, LEGO has leveraged itself as a major player worldwide, also constituting around 16.2% of the total toy market share in the Netherlands. It has also given rise to various LEGO-like competitors and various clone brands such as Blox, Click Brick, Gudi etc.

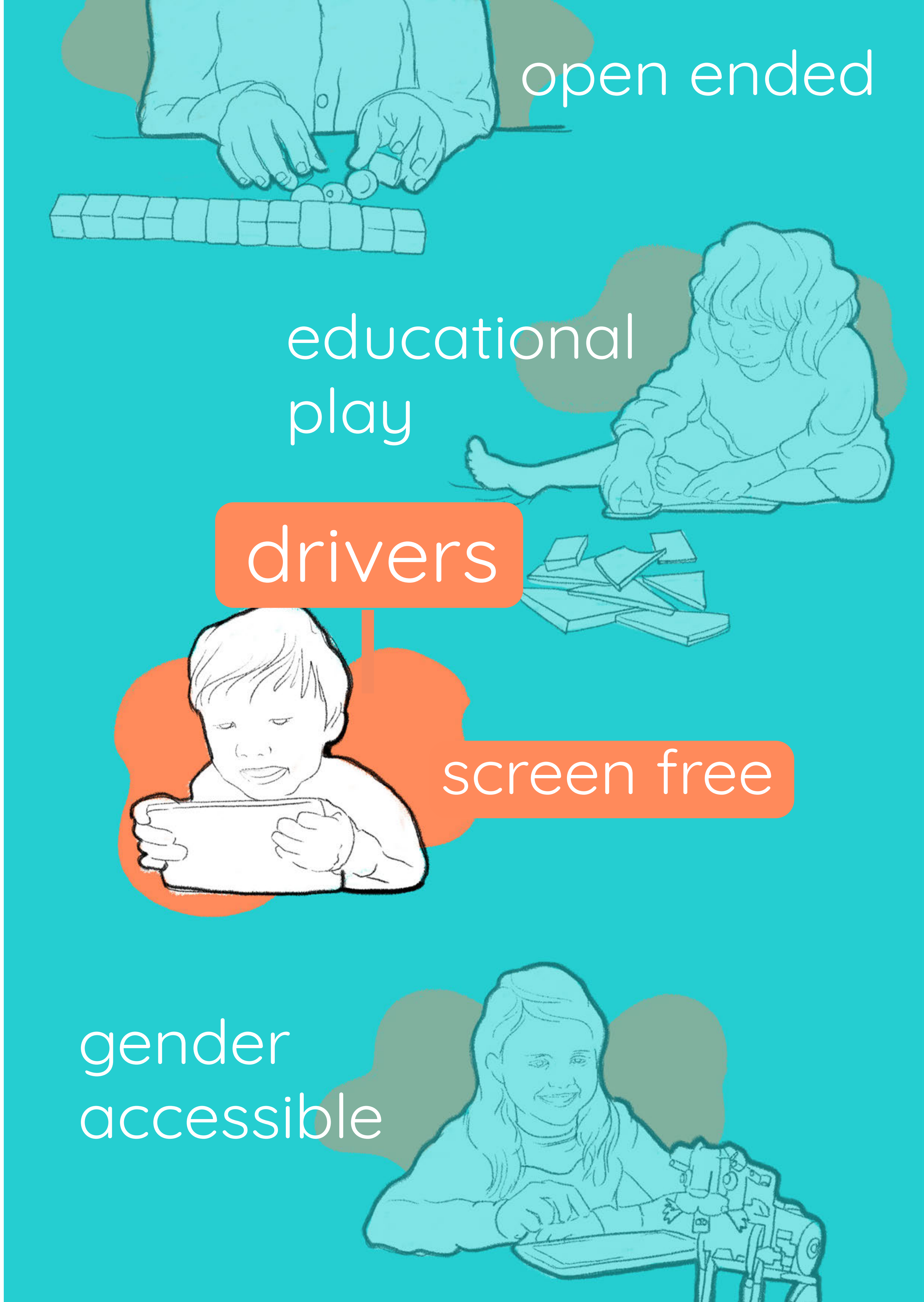
Owing to its foothold, there has been various products entering the market which have compatibility with the LEGO ecosystem making it easier for kids to combine and explore with examples
R32 of Flexo, InflatiBits, Brik Tiles etc. This is also encouraged by the active community around LEGO universe such as the active reddit communities, LEGO Life and so on.

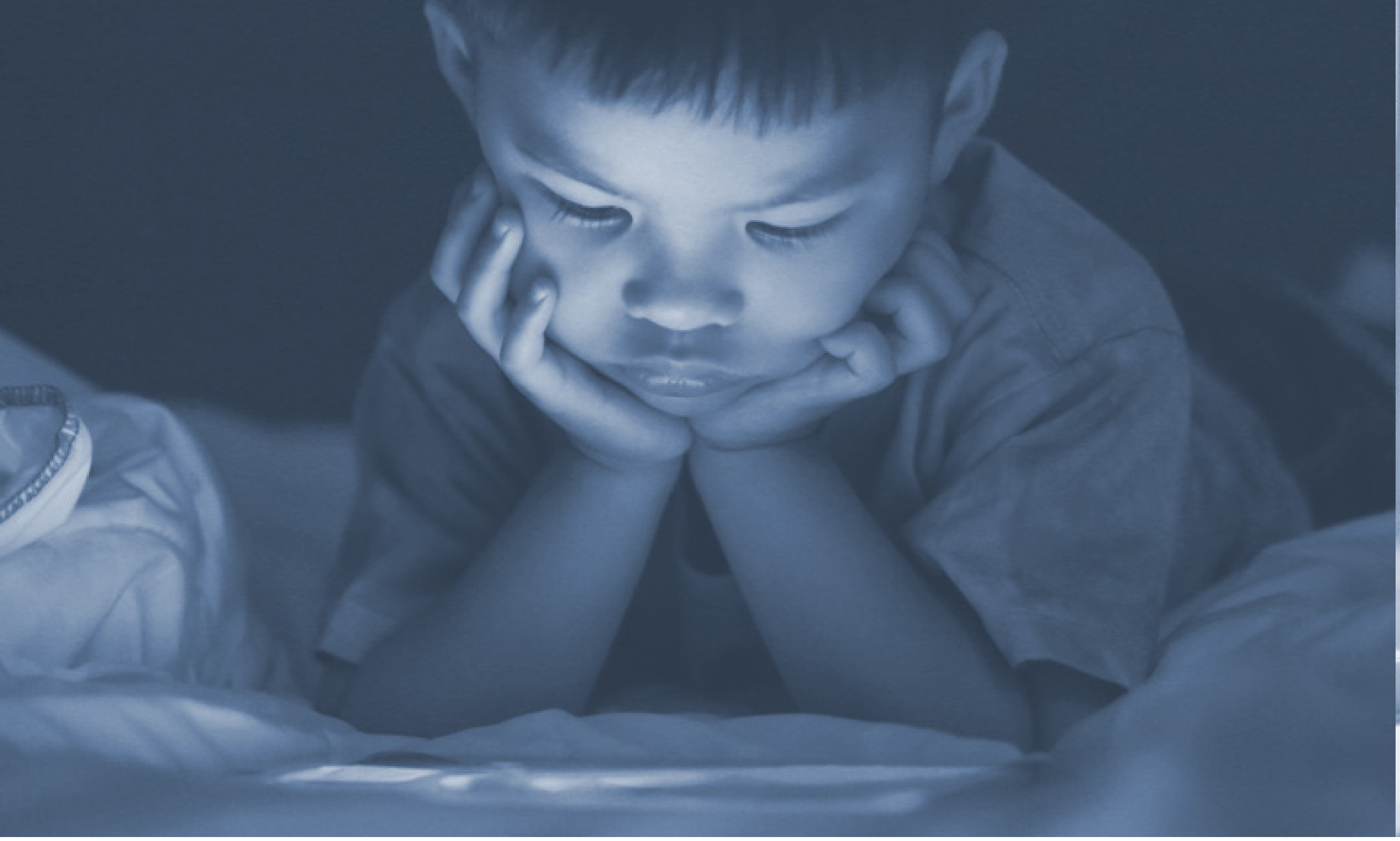
With the boom of innovative LEGO accessories, LEGO-compatible companion kits, and LEGO add-ons, it is bringing much more versatility to the play. Most of the products require you already own bricks and other standalone kits, with most of them being 100 percent compatible with LEGO, Kre-O and Mega Blox.

However, despite the surge in the robotic creation kits, ranging from large brands like LEGO Mindstorms to startup companies such as Tinkamo and Microduino, most of them, if not all behave almost similary: mechanical, rigid, classy or 'robotic'. This makes it ripe for disruption and opening up more possibilities for various other types of play.









(Fig. 1.10.1) Directional operator blocks given as a probe to create coding logic to run a navigation bot

screen free

1.10.1

Most of the educational systems worldwide are resorting to screen-based education. Children spend on average 7 to 8 hours in front of screens every day and this is affecting their cognitive and social development. There is increasing number of evidences showing how increasing screen time is causing lesser healthy diet quality and poorer quality of life. (Stiglic and Viner 2019)

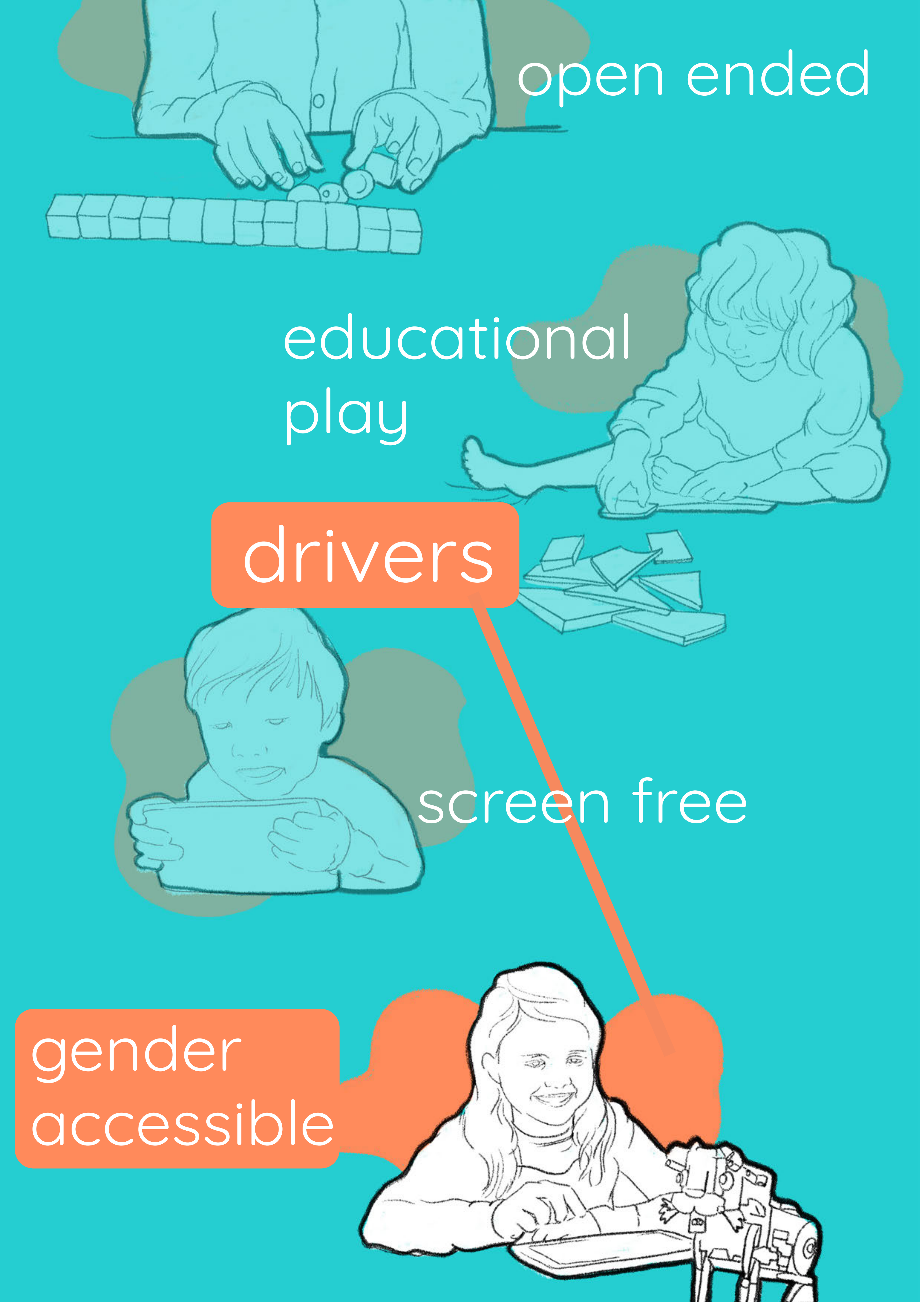
There is also evidence that higher screen time is associated with deleterious effects on irritability, low mood and cognitive and socio-emotional development, leading ultimately to poor educative performance. (Stiglic and Viner 2019) Owing to all these, it is generally suggested to reduce digital usage. The American Academy of Pediatrics recommends parents place a reasonable limit on entertainment media. Despite those recommendations, children between the ages of 8 and 18 average 7 hours of entertainment media per day, according to a 2010 study by the Henry J. Kaiser Family Foundation.

R33

There has been a rise in screen free products such as Cubetto, TACO Playbits and Cubroid.

Observational studies were conducted at De Bonte Bouwplaats to understand how they formulate logic using basic directional operators such as (left, right, up and down) to control a bot and the response was highly positive. This study gave insight as to how there could be wide variety of such screen free alternatives for fundamentally digital experiences for younger kids.

As the parents are highly receptive of such STEM based toys for younger kids to help them learn coding and logical thinking in a better way, it sheds insights on the end user persona (Chapter 3.5.1)



gender accessible

1.11.1

Medium is the message.

This is an important catchphrase coined by the Canadian communication thinker, Marshall Mcluhan attributing his focus of his study to the medium itself and how it affects society, apart from the message delivered by the medium which is often overlooked. (i.e in relation to television, newspaper, radio, internet etc)

Interestingly, this brings a lot of parallelisms with respect to the field of robotics itself.

If medium is the message, how could we change the medium in such a way that it brings about a message of gender accessibility? As we have discussed in the earlier chapters (Chapter 1.5) as to how robotics in itself is riddled by the conventional notions of what 'robotics toys' should look like, and should stand for. As to what boys should play with, and what girls shouldn't.

Soft robotics provides a platform to break free from the existing notions of what robots are commonly perceived as. And in this way, it provides a fresher lens with which gender accessible play could be designed without any extra baggage.

Apart from the change of medium which soft robotics in itself provides, it has tactile and experiential differences. Touch is so primal to our human development, and like all other higher mammals, human beings have strong intrinsic tendencies towards building basic communicative functions and attaching relationships through touch. In a sense, the softer feel may be pleasing or comforting to a person interacting with a robot, and may elicit a response of trust and openness. (Arnold and Scheutz, 2017)

With the medium as the message, eliciting such responses could accommodate more diversity to the accessibility of science and math toys.

1.11.2
what's the catch?

However, making soft robots is normally troublesome: you have to design the mold, make the mold (with 3D printing, for example), cast the soft materials (the most usual one is silicone), wait for the silicone layer to dry, stick the two layers of silicone together with more silicone and make sure it's air-tight, and finally test the inflation with air pump or hand pump. If essentially making itself is such a painful and arduous process, learning how to use such soft actuators would be even more frustrating for the children. R34

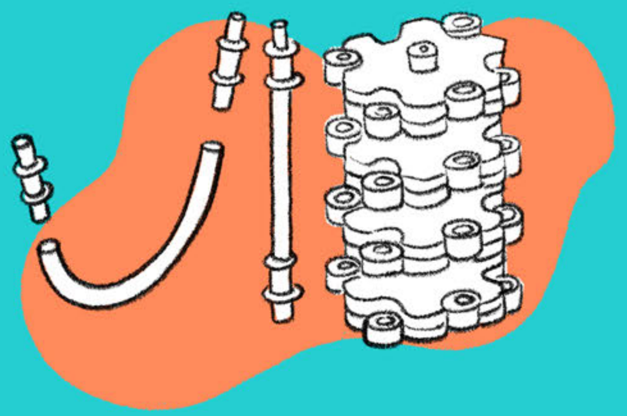
There has been advancements in developing modular blocks for soft robotics that could solve these fabrication hurdles and make it less frustrating and far more enjoyable for children to play and learn from by providing a bottom-up design platform for exploration.

For instance, Soft LEGO consists of pneumatically inflatable soft bricks, flexible bending bricks and channel bricks.

SoBL units were also developed to enable a bottoms-up approach, by allowing the end users to creatively and freely build various shapes of soft robots from modules with differing function. SoBL proposes a new way to integrate motion engineering units, connectors and non inflatable units without fitting into the LEGO ecosystem. (Lee et. al, 2016)

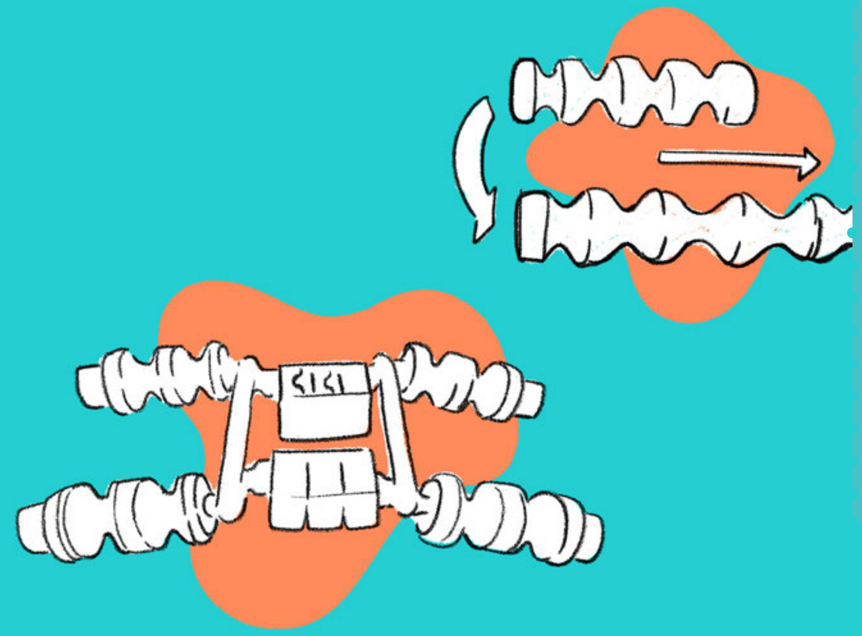
InflatiBits differentiates from SoBL and Soft LEGO in its ability to integrate with LEGO Blocks and making it more inclusive and versatile to combine the 'hard' blocks of LEGO with the soft blocks of InflatiBits. (Kopic and Gohlke, 2016)

On a larger perspective, it could be observed that although these soft modular blocks provide a very unique and different media of expression, they have still not arrived at a point of gender accessibility, as they are pretty much constructivist in nature (i.e based on stacking objects in different ways) and have to accomodate an element of storytelling and roleplay to make it more interesting for both the genders.



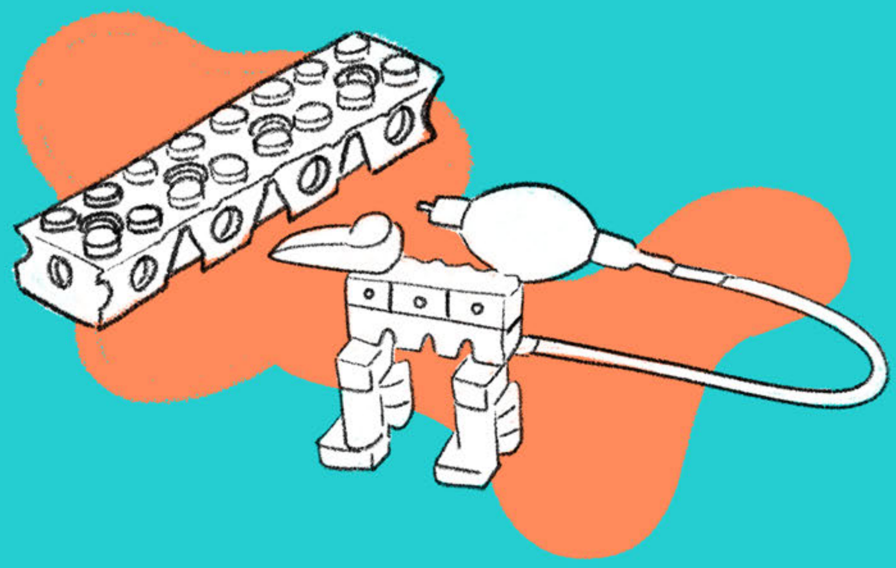
InflatiBits

+ Possibility to combine in various arrangments
- Frustrating to combine the blocks with each other
(Kopic and Gohlke, 2016)



SoBL

+ Possibility to combine and inflate both translational and rotational
- Not LEGO compatible
(Lee et. al, 2016)



Soft LEGO

+ LEGO Compatible
- Not having interlocking freedom as compared to the alternatives
(Lee et. al, 2018)

vision

1.12.1

To provide a gender accessible way of providing robotics education for children aged 4-7 by giving them a feeling of EXCITEMENT and AUTONOMY through play.

list of requirements

1.13.1

The list of requirements essential for designing the product are formulated based on two main factors. Primo, the concept drivers which form the basis of the vision and successive product development. Secundo, the basic essentials and criteria while designing technology for children which needs to match and comply with.

concept driver based requirements

open ended play

Should be LEGO like (or) LEGO compatible based on modular blocks which are subtractive or additive in nature (R05, R10, R13)

Should provide an initial set of play based instructions to provide reference inspiration to help children understand the possibilities through the product (Gelderblom, 2016)

Should be able to fit information into existing schemes (assimilation), adapt existing schemes so that new information finds place (accomodation), and combine existing schemes to form complex schemes (organisation) (R17)

There shouldn't be a right (or) wrong way to play, the outcomes should be left open for the child to interpret. (R29)

Should provide supportive scaffolding (R30)

The environment provided by the design should be forgiving and should provide guidance when required (R29)

gender accessible

Providing gender accessible characteristics in the form of the product. It should spark equal interest in both the genders (R01)

Should provide both roleplay and constructive play as a means of engagement (R03, R11, R15)

Should be aware of the stereotype threat and consciously steer away from conventional male cliches such as power, competition, destruction and speed (R04, R18)

Should use gender-accessible colors (Appendix B.7)

screen free

Basic interaction with the product should be possible without any screen based interface (Chapter 1.10.1)

Should provide a therapeutic experience through the tactile combination of plush surfaces (R09)

educative play

Should take into account the cognitive development of children in the age group of 4 to 7 years of age (R06)

Should involve soft actuators which can inflate/deflate and perform various motions (R09)

Should consist of basic building blocks which perform as manipulatives which are self-correcting (R10)

Should have a storytelling element with which they could perform psychological causality and relate to the characters (R10)

Should provide content and pedagogy required for active problem solving(R19)

Help the children understand the basics of this new academic field of soft robotics by allowing the possibility of motion design through the combination of restricting and extending elements. (R07, R08)
Should be easy for teachers to understand the product features and to guide the students in making creations using this kit (R19)
Should take into account the eight pedagogical principles during evaluation (R20-R26)

safety

The product should be operated by mechanical forces enough to not cause injury on misuse

The product should not have any sharp edges

Should comply with the Toy Safety Directive (Council Directive 88/378/EEC) in terms of flammability, chemical properties, physical and mechanical hygiene

child friendly design requirements

reliability

The product should not tear by normal stretching or squeezing by the children of the 4-7 age group

The product kit should be able to bear a fall upto 2m

The basic building blocks should be bigger than 3.5 inches square * 1.5 inches thickness (R13)

The product should be IPX2 compliant

The internal components should not be affected by environmental factors such as temperature and dust

interactions

Should be possible to engage with the object with moderate amount of hand dexterity

The user should be able to use the product for one hour without any significant fatigue

wishes

Should be able to active feedback on touch based gestures (R13)

1.13.2
quick recap of explore phase

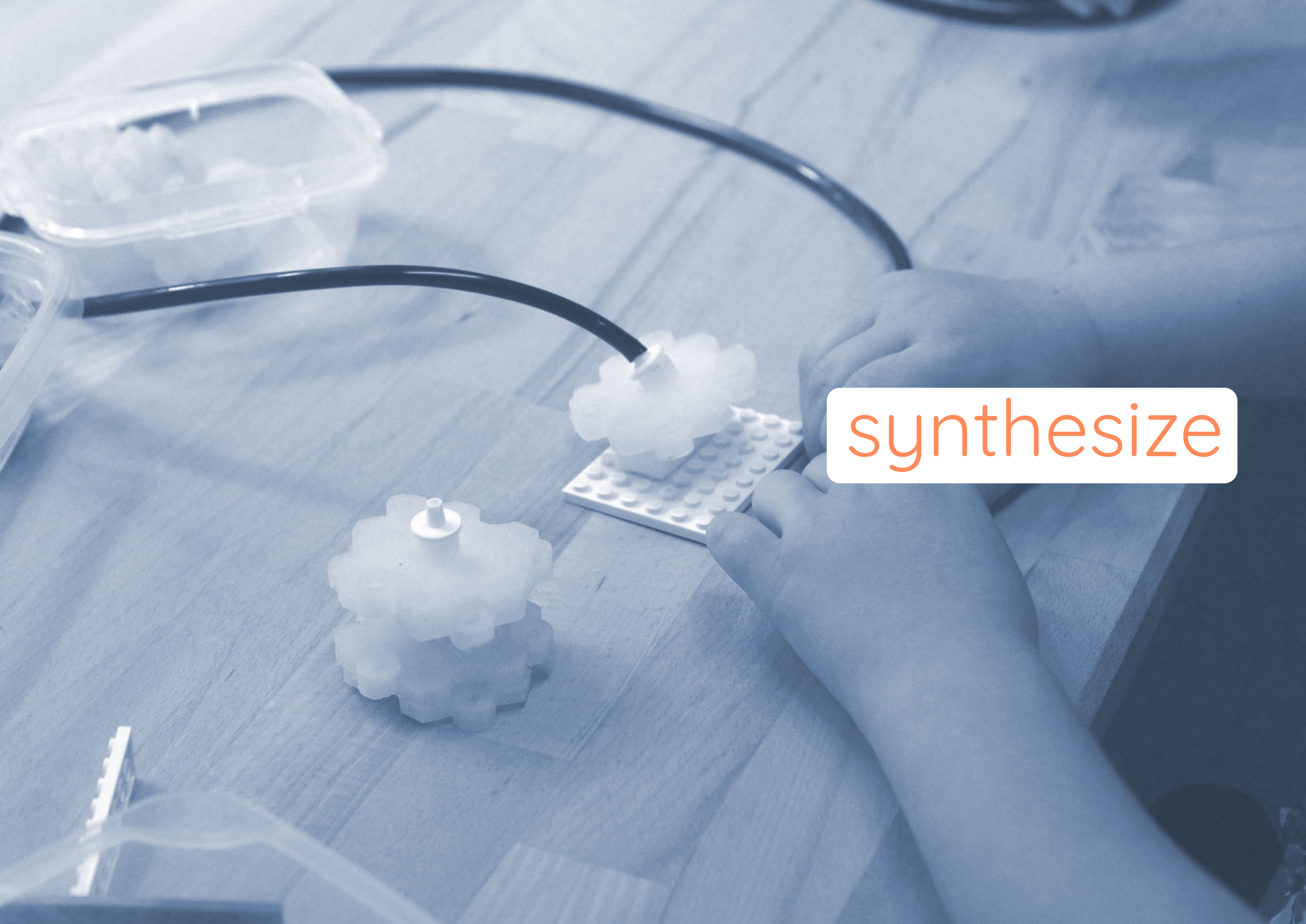
In the explore phase, with the pre-defined scope of the concerned age group of 4-7 years of age, various concept drivers are charted out such as gender-accessibility, screen-free, educational play and open ended play.

Owing to the closeness to the rationale behind the thesis itself, GENDER ACCESSIBILITY is selected as the key concept driver. In this aspect, the design guidelines needed for gender-accessible design are mapped, and the connection of gender-accessibility with soft robotics is investigated.

In OPEN ENDED PLAY, the philosophy of constructivism is explored with LEGO as a case study. The chapter then goes on to investigate the current trends of LEGO-based, LEGO-compatible toys, STEM toys and how robotics related toys could contribute to the holistic development of the child being inclusive of various pedagogical principles.

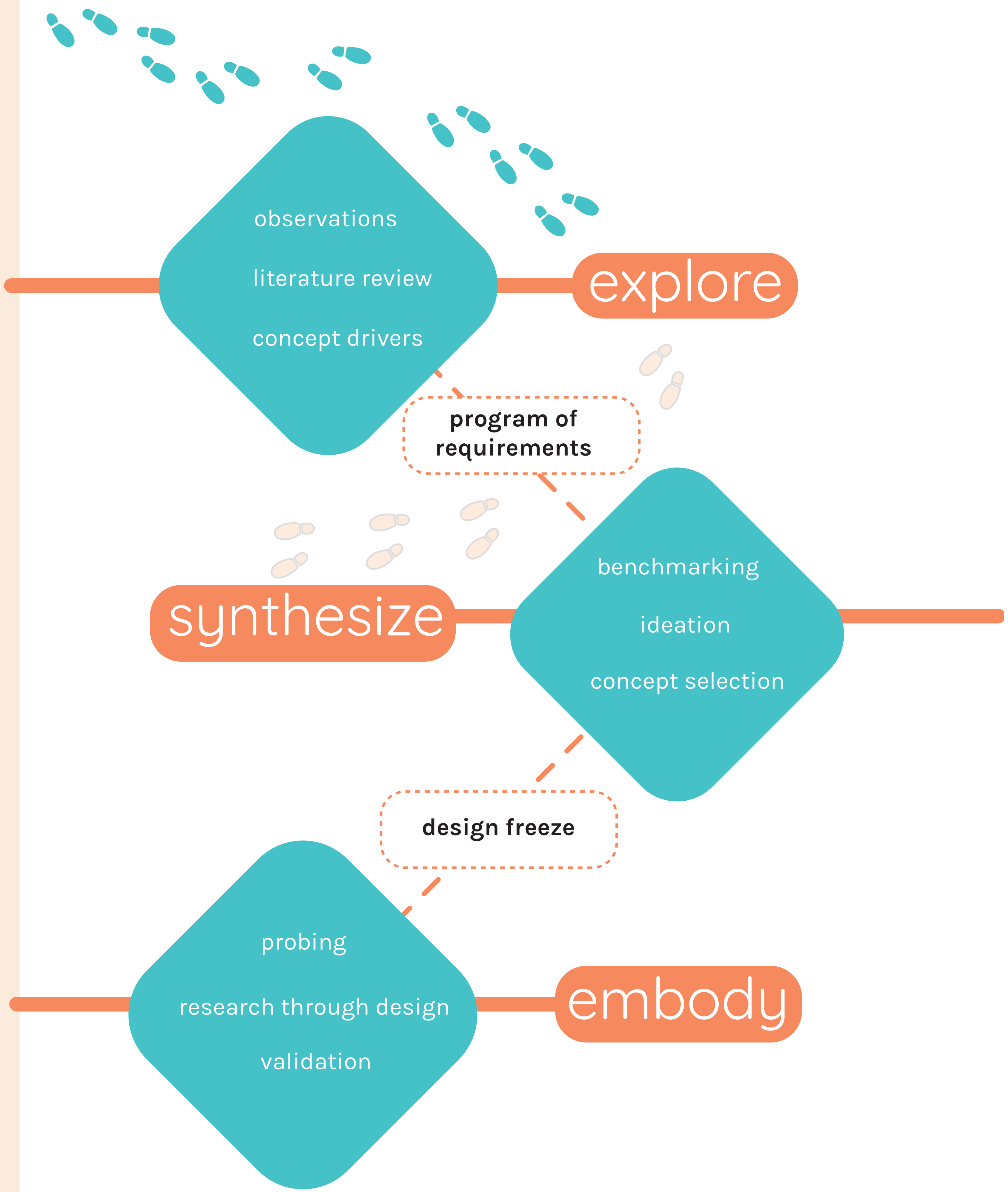
In SCREEN FREE, the disadvantages of screen dependence are explored along with the current trend in screen free alternatives for various traditionally digital experiences.

In EDUCATIONAL PLAY, the investigation goes a bit deeper, into the minds of children themselves. How do they think? What do they learn? What do they like to play with? These are the fundamental questions which are explored to shed some insights on the necessary design requirements which can help in ensuring that the designed product satisfies the learning outcomes.



synthesize

Synthesis



2.1 overview of the synthesis process

After having formulated the vision along with the program of requirements, in the synthesis phase, benchmarking of existing research/technologies/commercial products is executed (Chapter 2.2) and (Appendix B.5). In parallel, the idea generation and compilation of various concepts are done in a very iterative manner, taking into account newer insights in the design cycle. At the end of the synthesis phase, three main concepts are arrived at, and are successively evaluated based on the program of requirements to arrive at a selected concept which is successfully validated in order to arrive at a design freeze.

Although the design process happened in a very fuzzy back and forth manner in terms of analysis, synthesis and simulation happening in parallel, the following chapter is purposefully arranged in a non-linear manner, giving a narrative to guide the user through the design journey in hindsight.

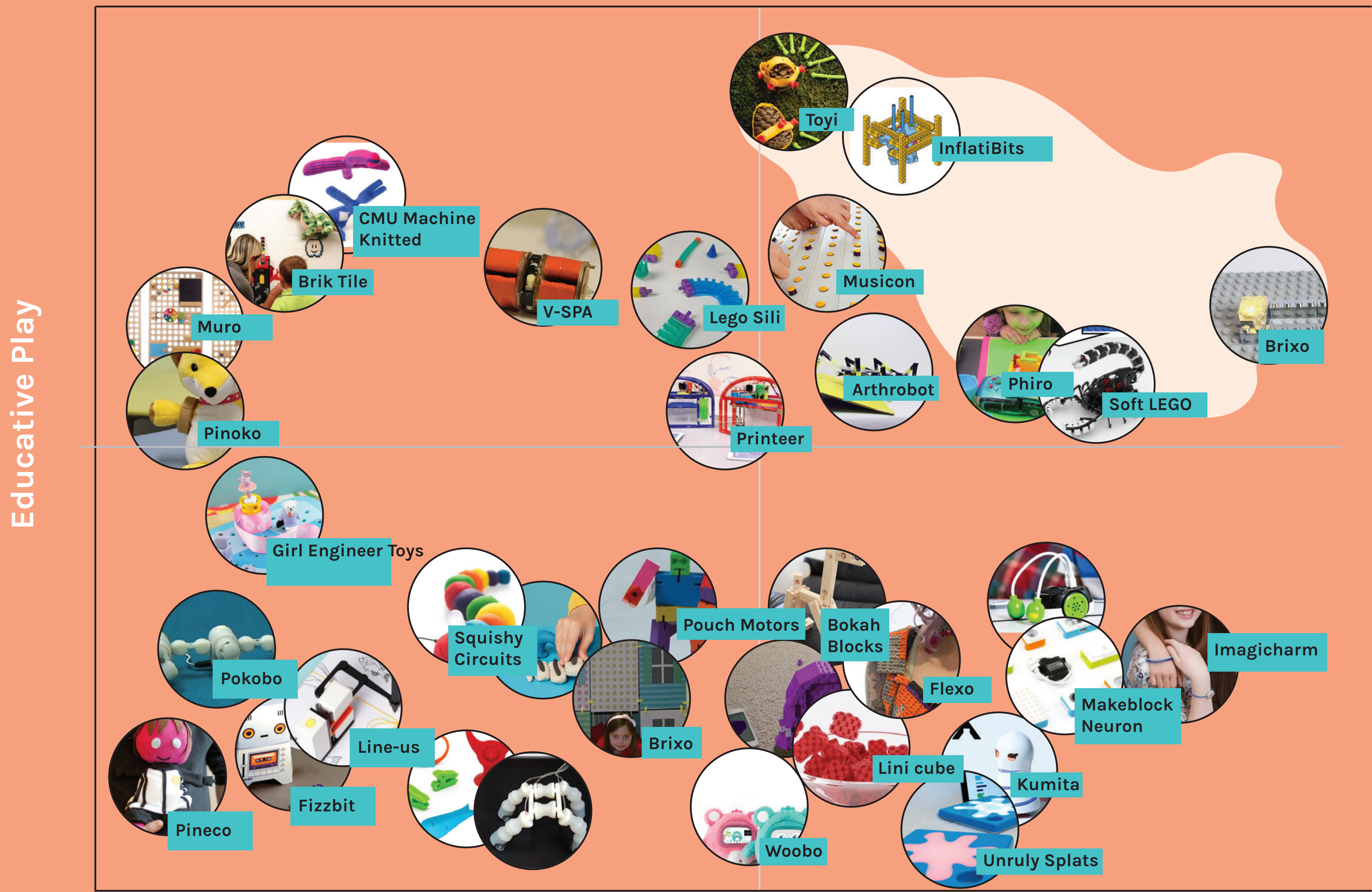


Fig. (2.1) Benchmarking of various STEM based toys on open ended play versus educative play

Screen free toys

Cody Bloks

+ Easy to learn coding
- Not LEGO Compatible

LoCoMoGo

+ Coding through play for younger kids
- Not open ended, modular

Cubetto

+Helps understand basics of coding for kids aged 3+
+ Curriculum designed for coding

Girl friendly

Goldieblox

+ girl-centered product design
- providing reading and building play, but less open ended

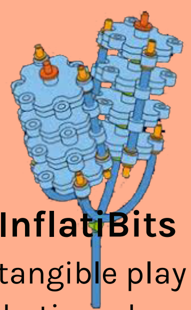
Jewelbots

+ coding using wearables
- not screen free
- less tangible play

LEGO Compatible

LEGO Sili

+ gender accessible design
- providing reading and building play, but less open ended



InflatiBits

+ tangible play for soft robotics education
- less child friendly interconnectors

benchmarking

2.2
screen free

Especially for helping younger children learn coding, the screen free nature of the toys such as Cubetto, Cody Bloks, Storyball, LoCoMoGo is in high need, as it helps keep them away from screens. Parents want their children to involve in physical activity and move away.

girl friendly

Choice of colors play a major role in drawing attention of both the genders towards the products. In GoldieBlox, specific colors are used to give focus towards girls. Not just that, the medium of storytelling used becomes equally important when it comes to gender accessibility. For instance, Jewelbots creates the narration of bonding through jewel-like bracelets for helping the children understand the basics of coding, IoT education.

LEGO compatible

To bring in more variety into the types of play using LEGO; to change the perception that playing with LEGO is all about being hard and mechanical, there is a rise in soft compatible units which can add onto LEGO to provide both soft and hard play.

Further details about the detailed benchmarking is further illustrated in (Appendix B.5)

ideation

2.3

The benchmarking method of categorising various products currently being made available for kids in the age group of 4-7 was used as an inspiration to explore various ideas, and as a means of brainstorming.

By combining various research explorations and products firstly based on themes and evaluating them based on the list of requirements (Chapter 1.13.1), ideas for concepts were selected.

The process involved exploring analogies, and trying to force fit connections between the analogy and the original problem statement (vision) along with its accompanying concept drivers. The outcome of this method was a preliminary set of ideas which were later on fine-tuned into concepts.

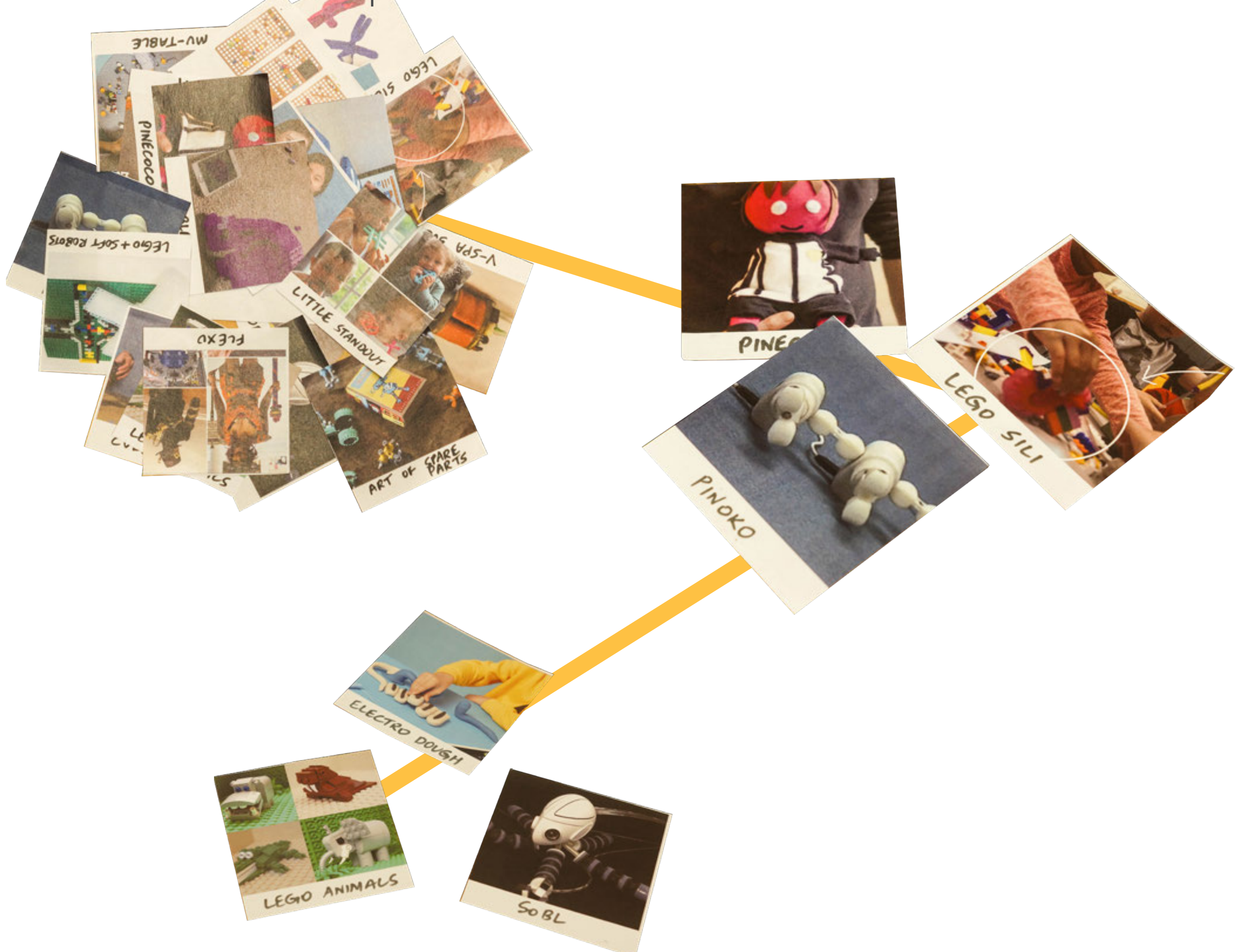


Fig. (2.3) Benchmarking of various STEM based toys on open ended play versus educative play

initial sketches

2.4

From the preliminary ideas generated out of synectics, the initial sketches were used primarily as a mode of metacognitive exploration, to visualise and understand one's own thinking behind the sketches. This served as a low-fidelity medium for critical thinking and to test the feasibility of the concepts through the sketches.

As explained in (Kollmer, 2020), sketching provided a back-and-forth medium through the design cycle process itself.

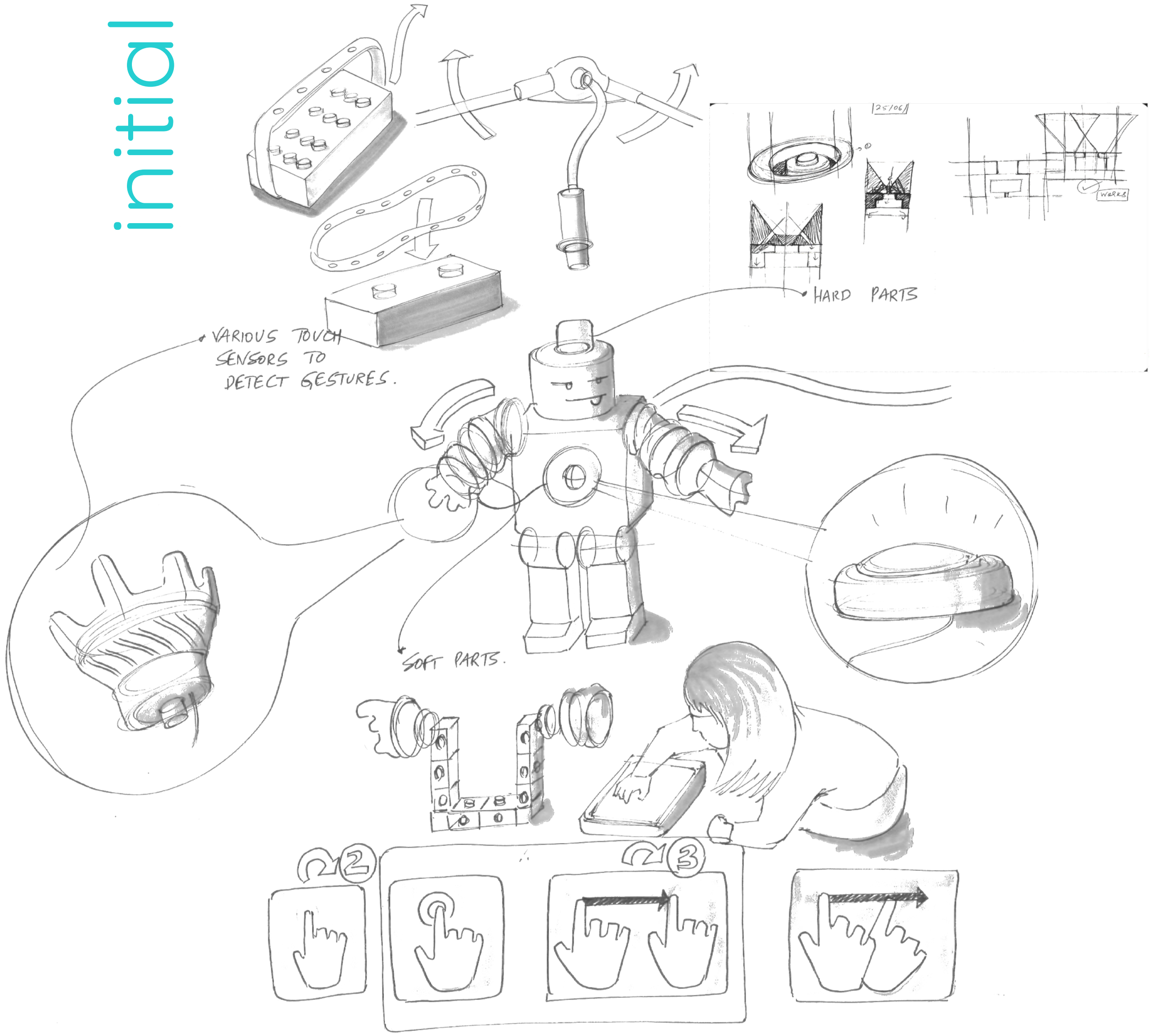
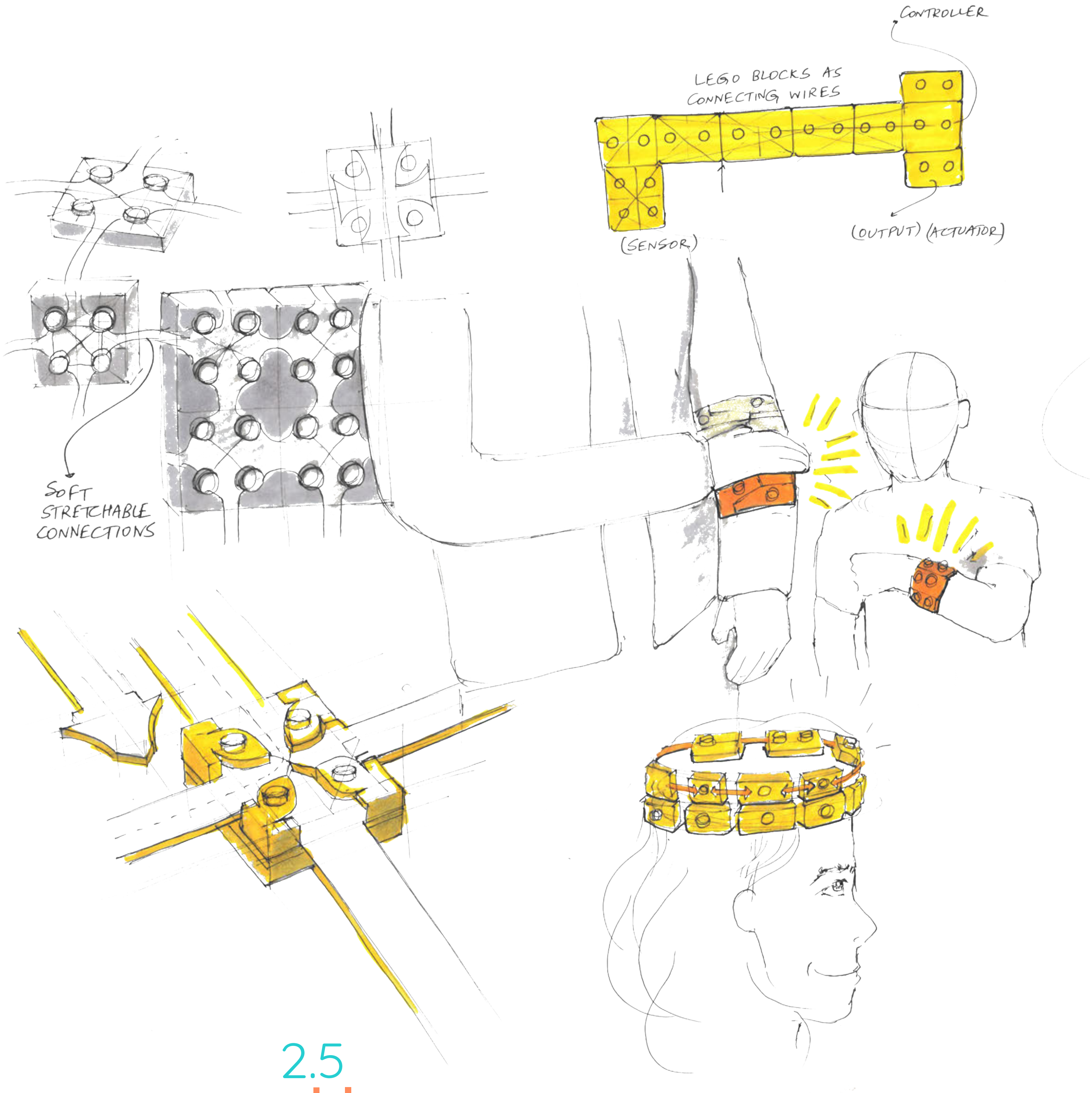


Fig. (2.4) Metacognitive exploration through drawing for various functions, subfunctions of the preliminary ideas

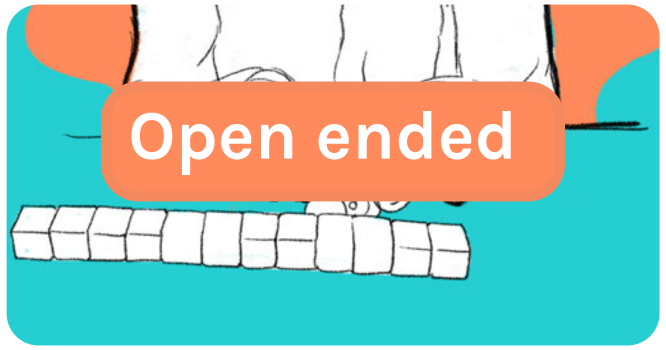


concepts

2.5
ablo

Ablo is a LEGO-like flexible connectors which can connect in a wide variety of ways for being used as wearables for children. Children could go on to make various wearables that could aid in their storytelling. Apart from this, Ablo also comes with optional add ons with sensors and actuator blocks which could then be coded using an app based interface.

In relation to the concept drivers



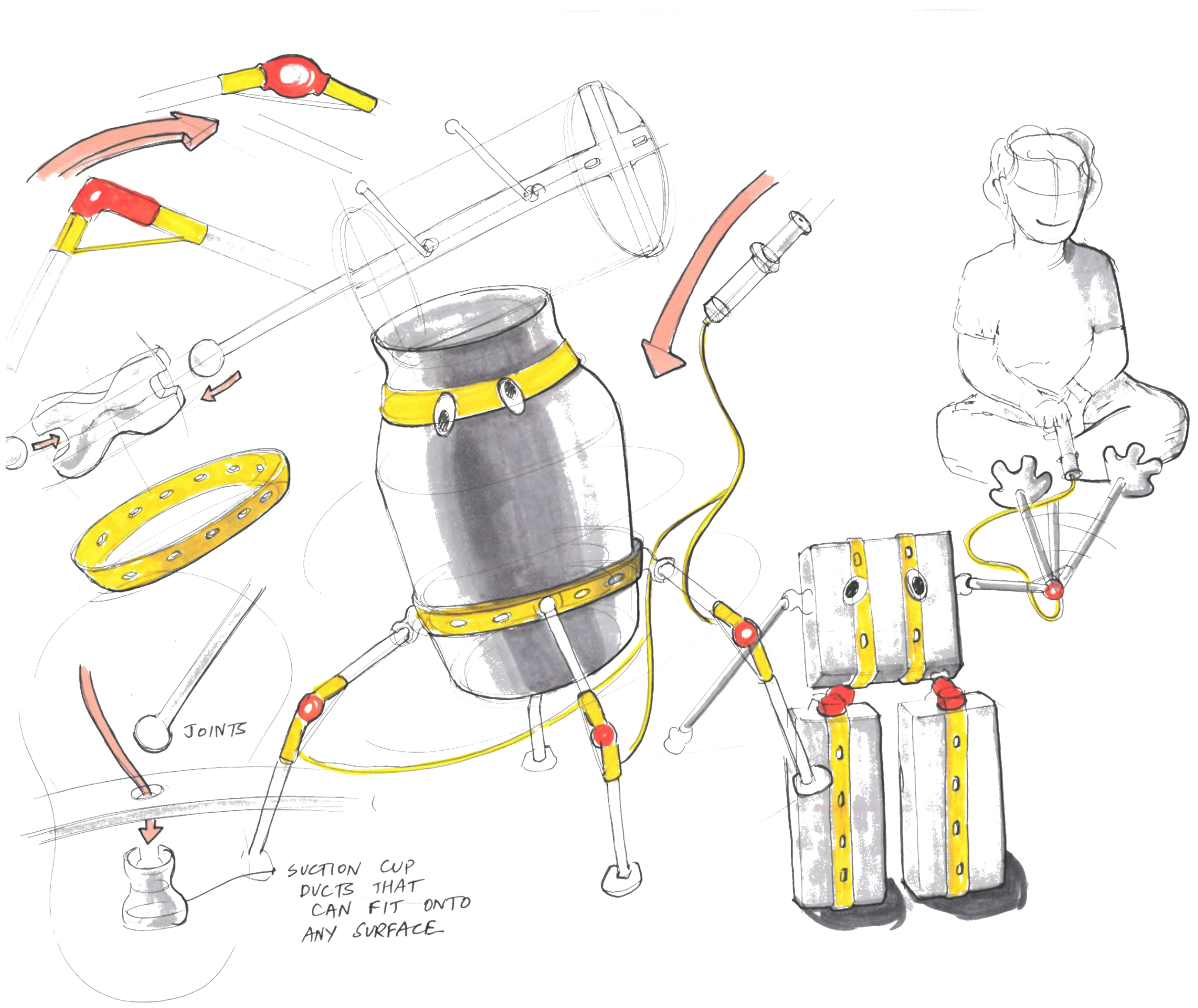
+ Possibility to connect in infinite combinations by means of the flexible interconnections.

+ Educational outcomes involve specifically cause and effect relationships through sensors and actuators.

-/+ Not possible to go screen free as it might require a tablet interface, and would involve blended learning (Hanning, 2018)

+ Wearables for communicating with friends has been quite trending among girls owing to the possibilities of storytelling (R01) and as it involves constructive play, it would be interesting for boys to involve in this play too.

concepts

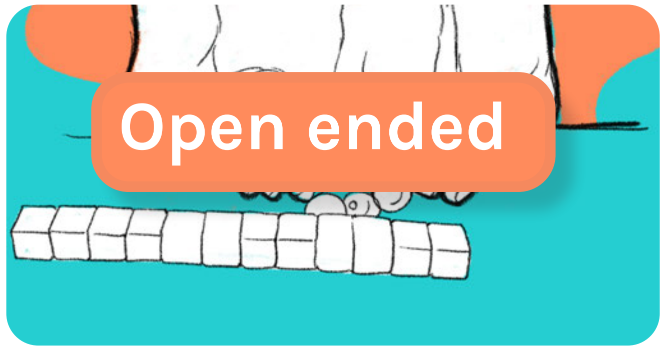


curio

This consists of easy to use blocks which can be plugged into LEGO make-pieces of any other everyday objects using easy to use elastic connectors. Children go on to make various multi-legged objects which they can direct to perform various experiments on locomotion by means of inflatables.

Multiple inflatables could then be connected to perform a series of movements by the object at hand.

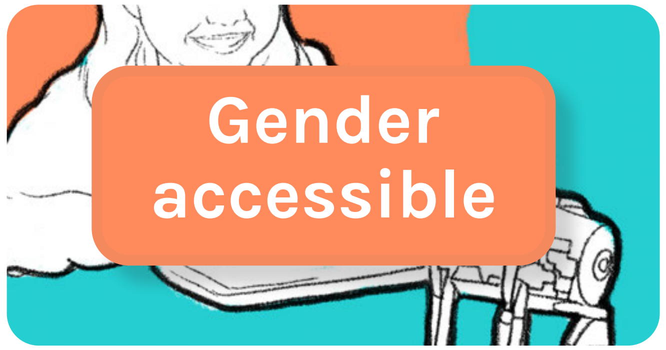
In relation to the concept drivers



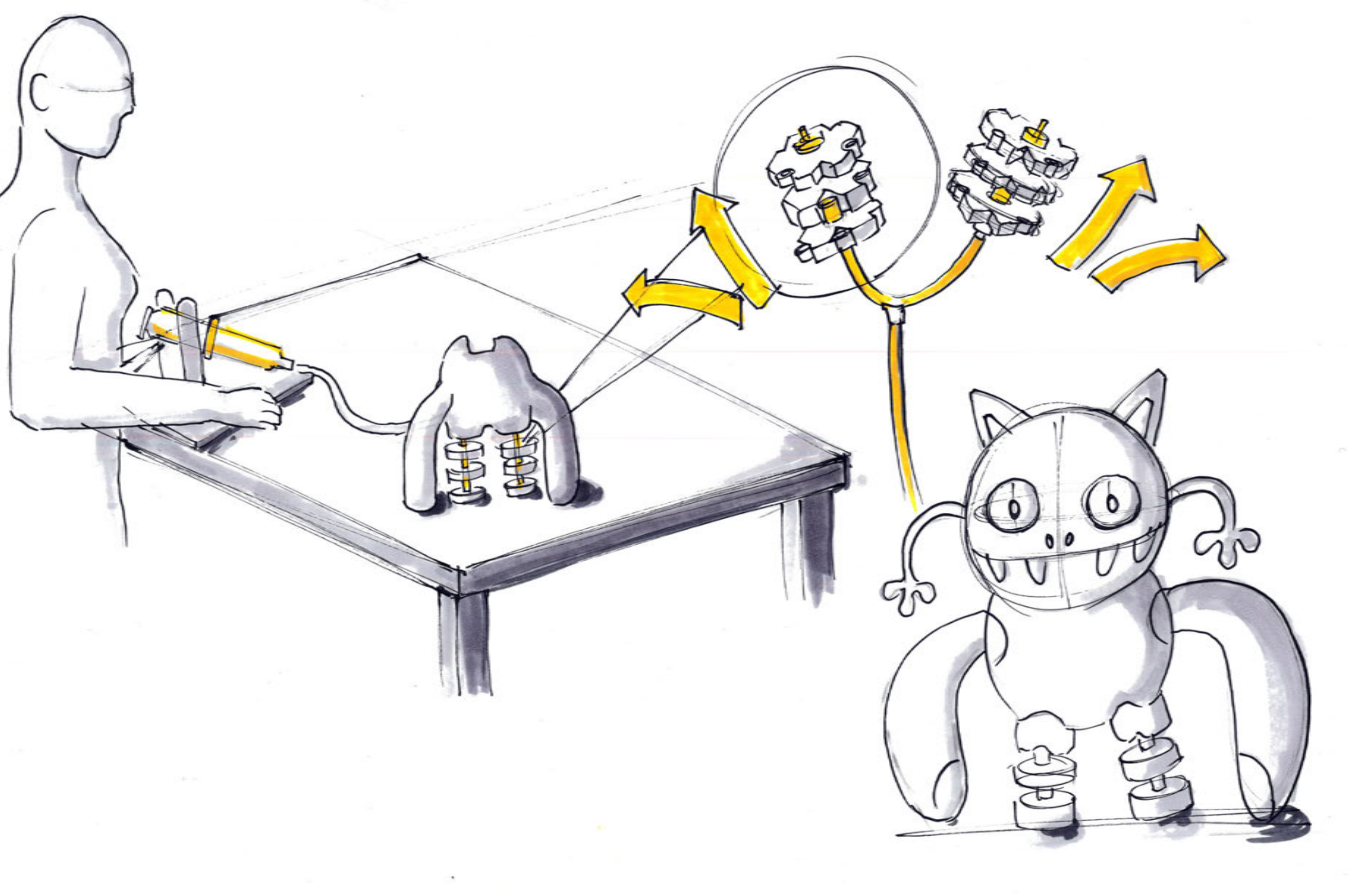
+ Possibilities to use any type of reusable materials ranging from toilet paper rolls, to milk cartons or even cardboard boxes etc

+ Understanding how to use flexible bending restrictors and soft actuators which form the basic fundamentals in the field of soft robotics.

+/- Possible to completely screen free. However for the future roadmap, it might fail to match up with the requirements with the need for hybrid play (ability to interface with a digital environment)



+ Can accommodate gender accessibility but might fall short on the ability to provide reference inspiration for starters to show the open ended possibilities involved. This might make it more frustrating for the user to come up with various ways to play and interact.



concepts

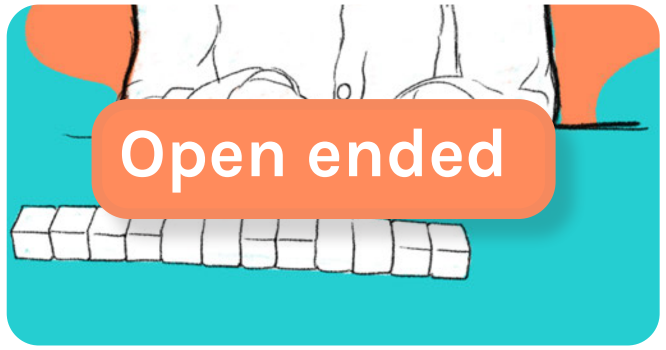
silly stompers

Silly Stompers consists of a base with various connectors to attach various 'limbs' made up of modular soft inflatable blocks. In this way, by making the silly stompers move in the way they want through a combination of the soft actuators and the restrictors, they learn the basics of soft robotics.

Silly Stompers consists of a wide range of possibilities for locomotion based on the way the modular blocks are connected. The hexagonal soft modular blocks allow for the capability in connecting in series, parallel, adjacent and side-wise. Being LEGO compatible, they can also make their own custom animals with LEGO parts thus providing more flexibility and open play.

Silly Stompers is based on the pedagogical principle of 'scaffolding', where the characters are given as a launchpad to create their own narratives using custom motions that allow in a wide range of interactions. However, if they would like to advance to the next stage, children could combine LEGO (hard) with the modular soft blocks helping in much more open ended and diverse outcomes.

In relation to the concept drivers



+ Possibilities to combine in all types of orientations with or without the need for using LEGO or other LEGO compatible alternatives which is a significant advantage.

+ Allowing in learning basic principles of soft robotics by means of inflating and bending actuators. Allows possibilities of roleplay and storytelling with a possibility to add sensor-actuator based cause and effect functionality later on.

+ Allowing possibilities of coding by means of air through tangible screen free play by means of soft plush surfaces. Capable of hybrid play later on by means of embedding sensors onto the modular blocks.

+ Changes the whole notion of what a robot means, by means of silicone based soft actuators thereby reducing the stereotype threat.

2.6

comparison of criteria in pairs

	Properties	1	2	3	4	5	6	7	Weighing factor
1	lego-like compatibility	x	0	0	1	0	0	0	1
2	accomodating roleplay and constructive play	1	x	1	1	1	1	1	6
3	provide open ended play	1	0	x	1	0	1	1	4
4	minimum screen based interaction	0	0	0	x	0	1	1	2
5	learning outcomes	1	0	1	1	x	1	1	5
6	accommodating child friendly design	1	0	0	0	0	x	0	1
7	providing tactile therapeutic experience	1	0	0	0	0	1	x	2

output of this method

From the three design concepts/principal solutions which were selected, the weighted objectives was used (Roozenberg, 1996) to evaluate and make a decision whether the design concept should be developed into a detailed design.

Each weight on the scale was assigned a value between 1 to 5, and the criteria were compared in pairs to attribute a weight factor, along with a total sum of weights of criteria, 100.

Among these concepts, Concept 3 (Silly Stompers) was chosen to proceed to the next stage of development. It was primarily chosen owing to the ability to the concept closely aligning with the requirements to be LEGO compatible, safer and easier to operate and fitting well with its utility in soft robotics education.

weighted criteria

Weighted criteria method is used to evaluate the three best concepts chosen as per the requirements mentioned below. They are then shortlisted and assigned weights based on the criteria. The total weights amount to 100 and are distributed according to their importance.

		concept 1		concept 2		concept 3	
	Weight	Score	Total	Score	Total	Score	Total
(i)	4.76	9	43	4	19	8	38
(ii)	28.57	7	200	6	171	10	286
(iii)	19.04	8	152	9	171	8	152
(iv)	9.52	6	57	9	86	10	95
(v)	23.80	6	143	7	167	7	167
(vi)	4.76	7	33	9	120	6	29
(vii)	9.52	6	70	7	70	9	86
			698		**804**		**826**

Fig. (2.6) Weighted criteria method for evaluating and selecting the concept for the next stage

conclusion

From the analysis of the existing toys in the market through the Benchmarking, it has been observed that there are no specific toys in the market focussing on soft robotic education.

Concept 3 (Silly Stompers), chosen for further development fits in neatly into this niche of soft robotics education, and could be a valuable entry into the toy market for 4-7 year olds.

Although there have been various research projects showcasing the potential of soft robotics such as SoBI, Lego Sili and InflatiBits, there could still be major updates possible in terms of making them more child-friendly and also gender-accessible.

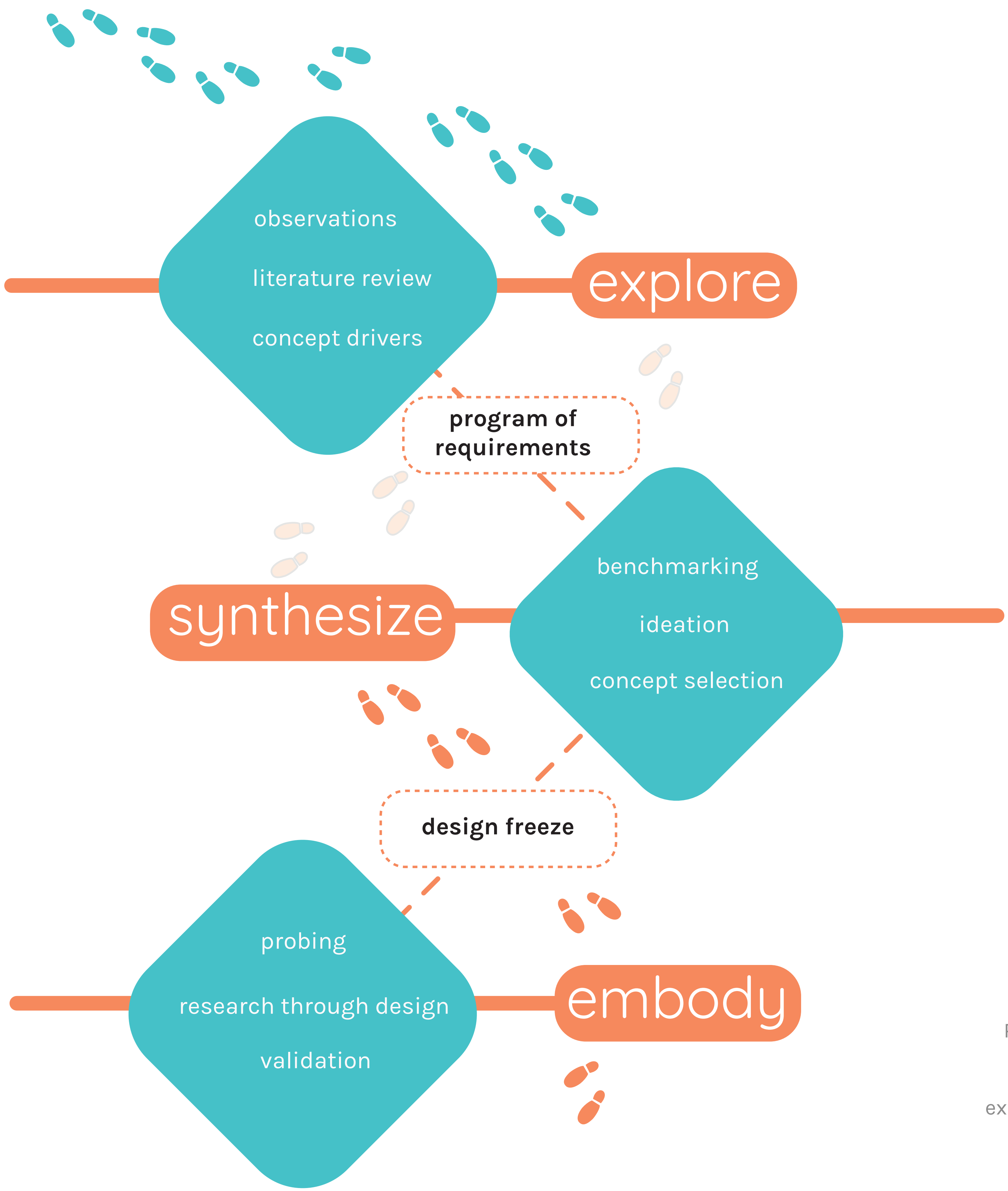
2.6.2

quick recap of synthesize phase

The Synthesize phase starts with the List of Requirements, and the Vision as the precursor. With this as the starting point, various ideas are generated for plausible concepts using predominantly two methods - benchmarking and synectics.

By the amalgamation of the two, three major preliminary ideas are shortlisted which are then evaluated using weighted criteria method. As the POC (Program of Criteria) is quite exhaustive when taking both the (Concept driver based requirements) and the (Child safety requirements), 7 of the most essential are taken to evaluate the required concepts and arriving at a decision. (Chapter 2.6)

embody



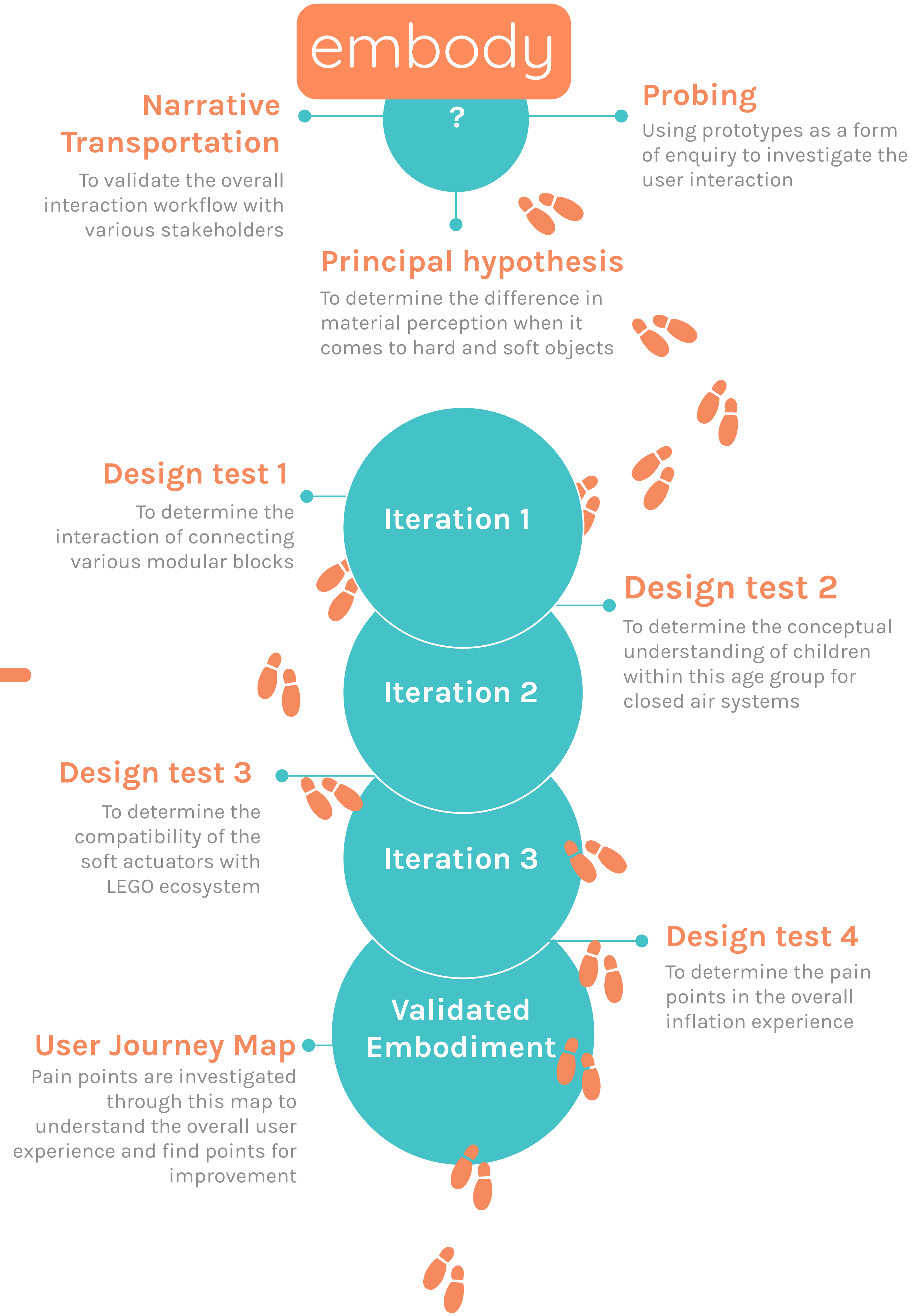
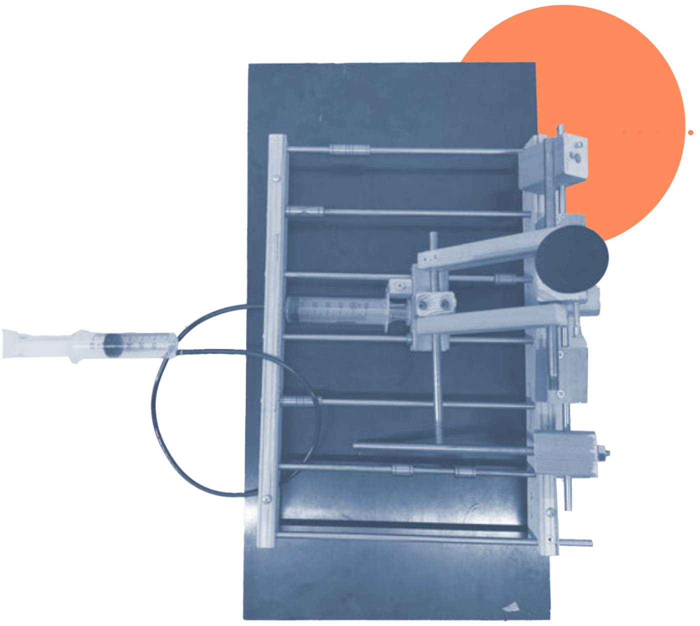


Fig. (3.0 a) Overview of the embody phase which includes validation through RtD (research through design)

probing

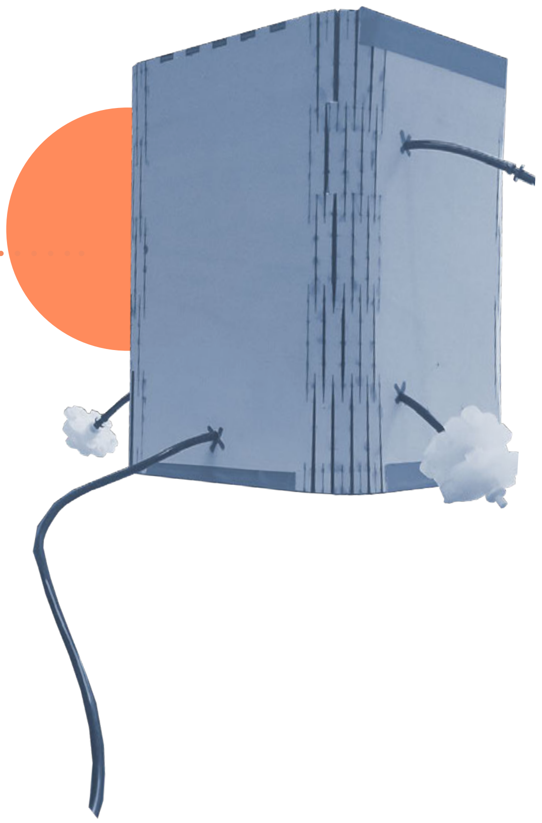
3.1

modular inflatable silicon blocks to examine how they interact to the tactile experience of silicone



syringe based pneumatic unit for understanding how well they could pump and inflate the bodies in various sequences

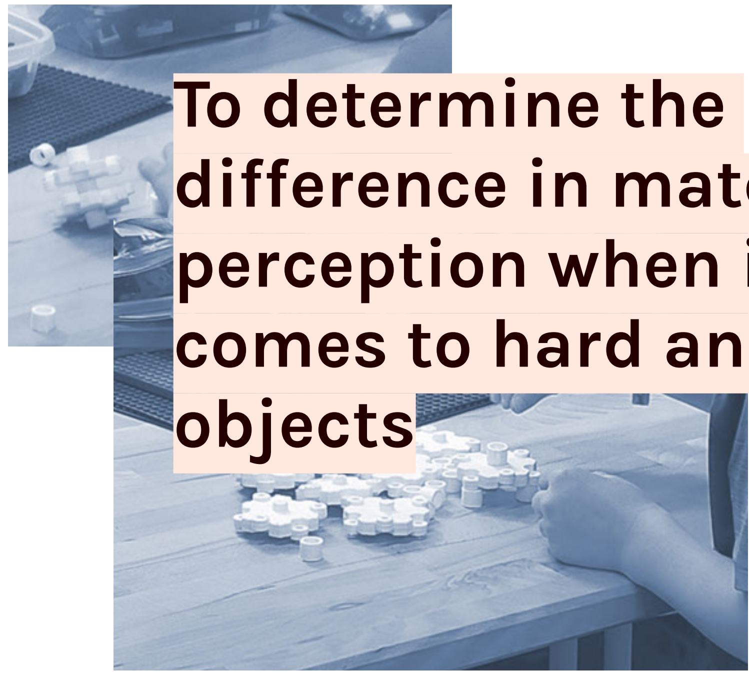
probe to examine how well the children could create and connect closed air systems



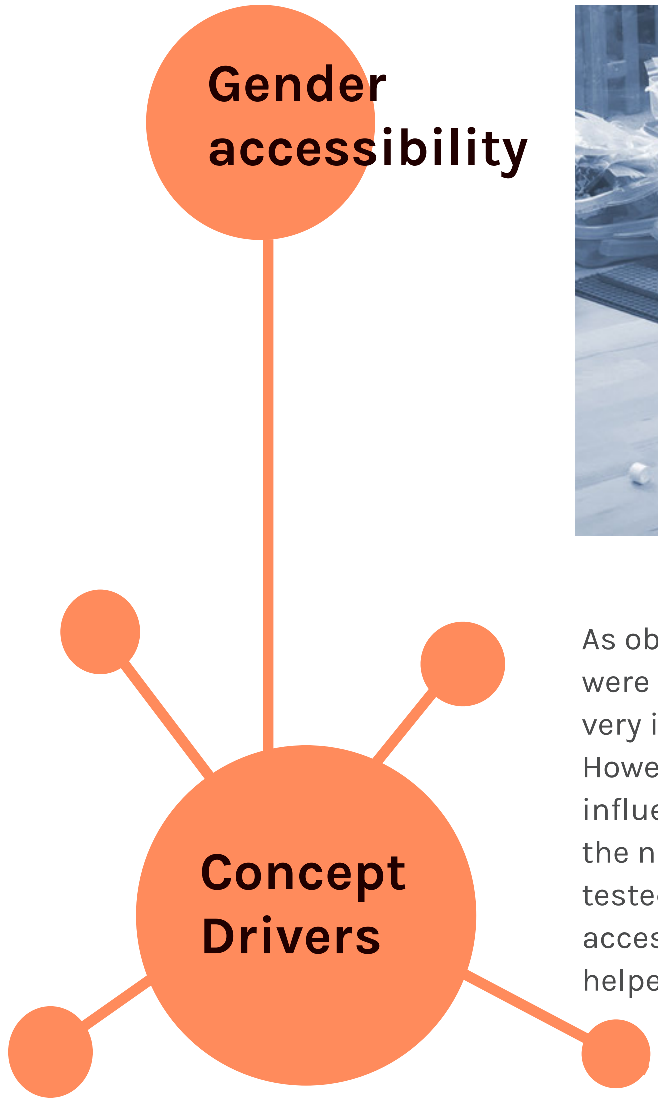
rigid hexagonal blocks given as a probe to understand how well they could involve in constructive play

design test 1

3.1.2



To determine the difference in material perception when it comes to hard and soft objects



As observed the soft squishy nature of the blocks were more friendly and accessible, providing a very inviting experience for both boys and girls. However, it was difficult to determine the exact influences owing to the limitations in terms of the number of participants this hypothesis was tested with. With respect to the overall gender-accessibility of the design, the PLATUi scores helped determine this. (Markopoulos, 2008)

Fig. (3.1.2 a) Lateral stacking arrangements were carried out

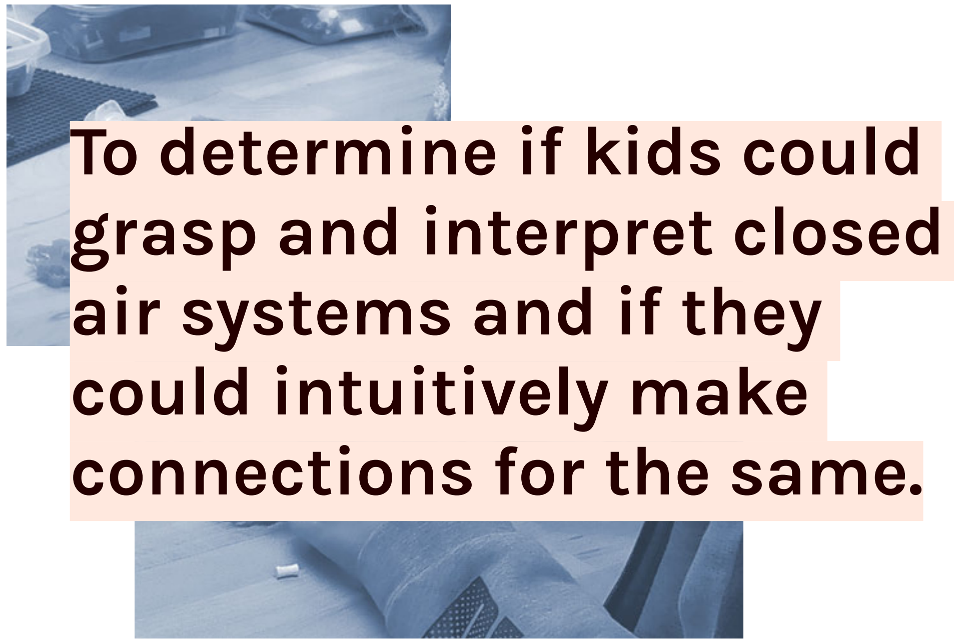
Fig. (3.1.2 b) Preferred material of choice (silicone) in comparison to PLA plastic

Fig. (3.1.2 c) Scope for open ended play through side wise, top down and lateral stacking of the blocks

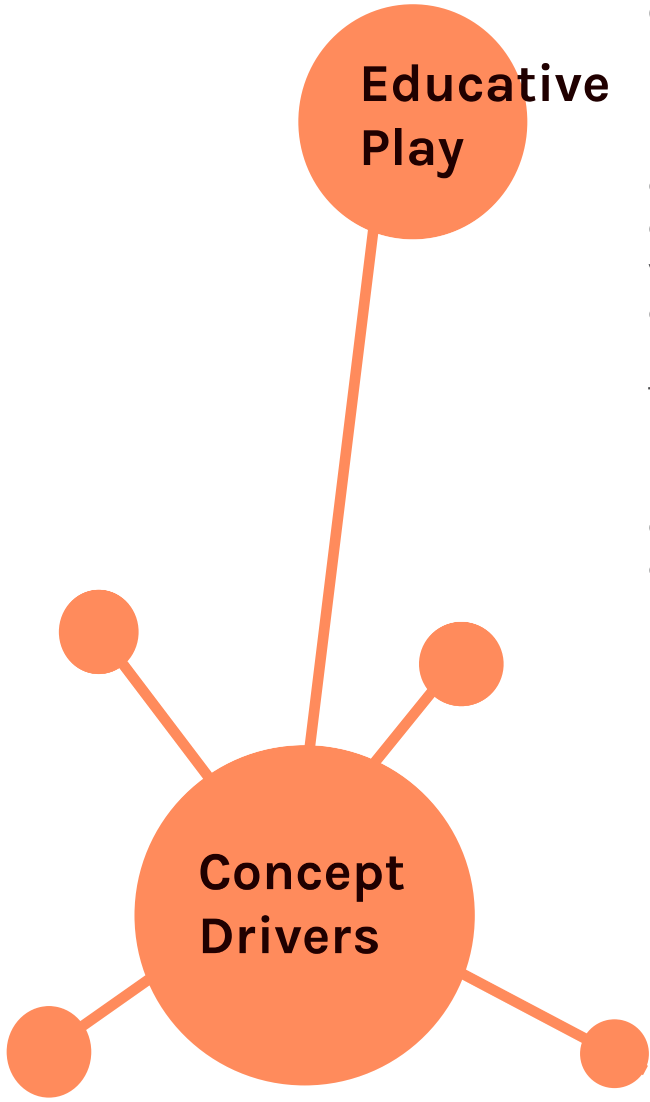
Fig. (3.1.2 d) Finding it difficult to pump the blocks using just one hand

design test 2

3.1.3



To determine if kids could grasp and interpret closed air systems and if they could intuitively make connections for the same.



Children understood closed air systems quite intuitively provided that they were given instructions or some basic inspiration as to how the system behaved. This helped them to create their own systems using the wide variety of modular blocks which could be stacked in various ways. This helped in providing more open ended play. (Appendix A.1)

This was in relation to Piaget's theory of learning by means of cause and effect were the child learns to create mental models based on observed behaviour of inflation, and learns to construct various systems in accordance to that. (R17)

Fig. (3.1.3 a) A normally open air system was quite difficult for children to interpret in the beginning. This was shifted to a normally closed system which could be opened if necessary

Fig. (3.1.3 b) The second iteration of the interconnectors were still difficult and frustrating for the children to connect and experiment

Fig. (3.1.3 c) It should be possible to extend the vinyl tubings to accomodate wide range of motion.

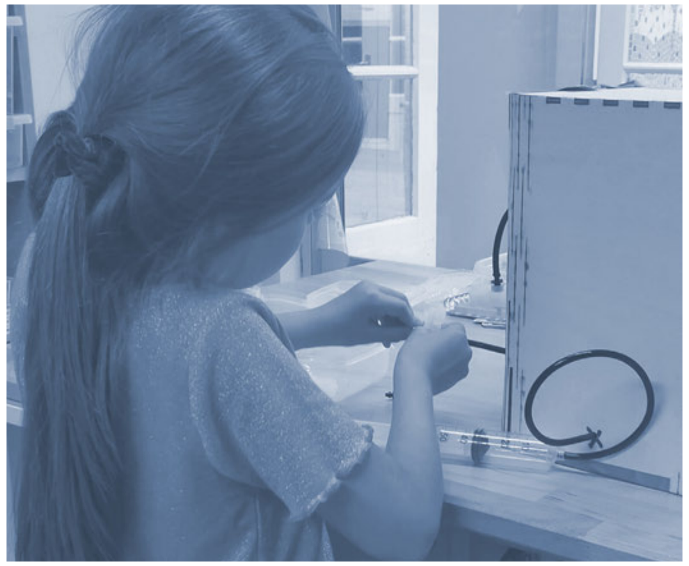
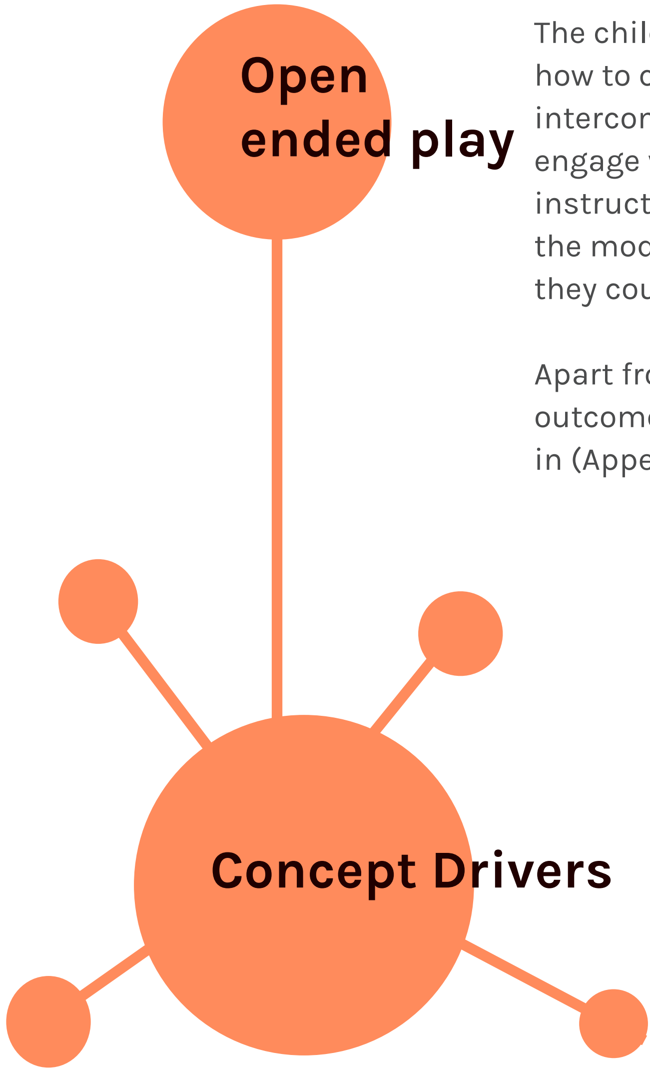


Fig. (3.1.3 d) Different limbs of the probe were connected to each other indicating how children were imagining air systems like a circuit to create various body movements.

design test 3

3.1.4

To determine if kids could interconnect the soft actuator blocks with LEGO to make their own designs



The children needed prior training in understanding how to connect the modular blocks using the interconnectors as this was pretty new for them to engage with. As a recommendation, an interactive instruction manual that could go hand in hand with the modular blocks is recommended, illustrating how they could combine and interact with.

Apart from this, there were various open ended outcomes that emerged through this activity as shown in (Appendix A.2)

Fig. (3.1.4 a) Using the LEGO based connectors to integrate into the LEGO ecosystem with the soft actuator blocks

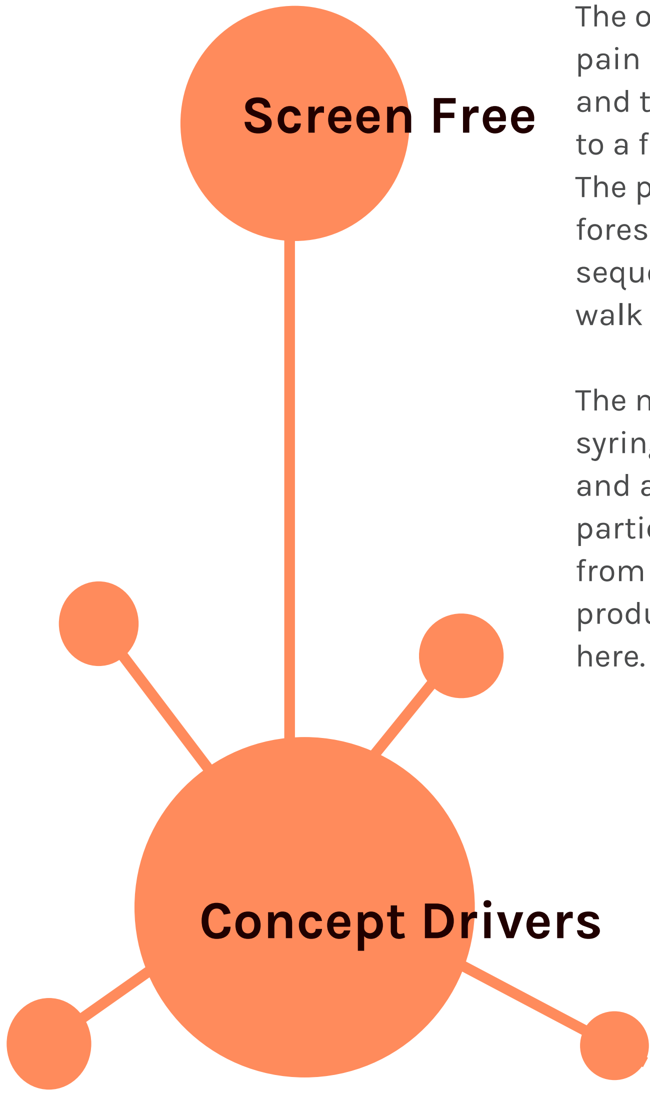
Fig. (3.1.4 b) The interconnectors were much more easier to combine the soft actuator blocks together

Fig. (3.1.4 c) It was still difficult to hand hold the syringes thus creating a need for a separate syringe pumping unit as shown

design test 4

3.1.5

To determine the pain points in the overall inflation experience



The objective of the test was to understand the pain points in the overall inflation experience, and to see if it provides a screen-free alternative to a fundamentally digital experience of coding. The probe used (Chapter 3.1) was made with a foresight of accommodating the creation of logical sequences that would help the Silly Stompers to walk in the desired manner. (Chapter 3.2.1)

The main takeaways from this test were that the syringe pumping unit should be made modular and allowing side-wise stacking so that multiple participants could engage with the product. Apart from this, the pain points with respect to the product interaction were also charted as shown here.

3.1.6
overall pain points

Fig. (3.1.6 a) Connecting the modular blocks to the limb connection points located in the body of the Silly Stomper

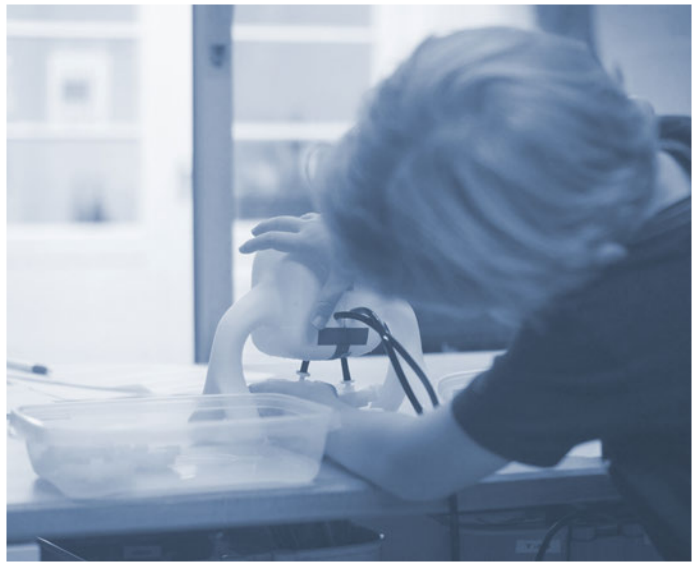


Fig. (3.1.6 b) Customising the body movement by connecting the soft modular blocks to bending restrictors

Fig. (3.1.6 c) Connecting multiple soft modular blocks as a stack

Fig. (3.1.6 d) The vinyl tube length was causing interference in the motion of the Silly Stompers which could be improvised

3.1.7
final validation

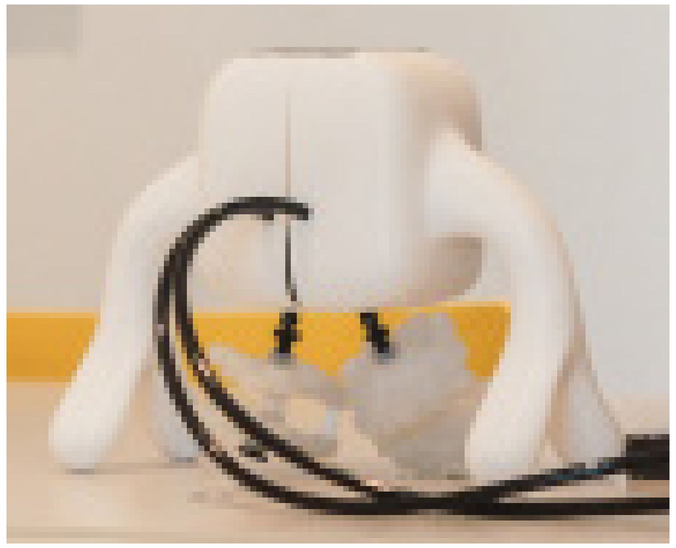


Fig. (3.1.7 a) Motion of the functional prototype of Silly Stompers actuated by pumping air in various sequences using the pumping unit

Fig. (3.1.7 b) Exploring various possibilities with LEGO. Here the participant makes a TNT type exploding device which breaks apart when you pump air into the contraption

Fig. (3.1.7 c) Participants showcasing their final outcomes both with and without using LEGO for play

Fig. (3.1.7 d) Based on the feedback received in design test 4, improvements were made to the interconnectors (Appendix D.4) which made it easier for kids to plug and play.

3.2.1
product interaction

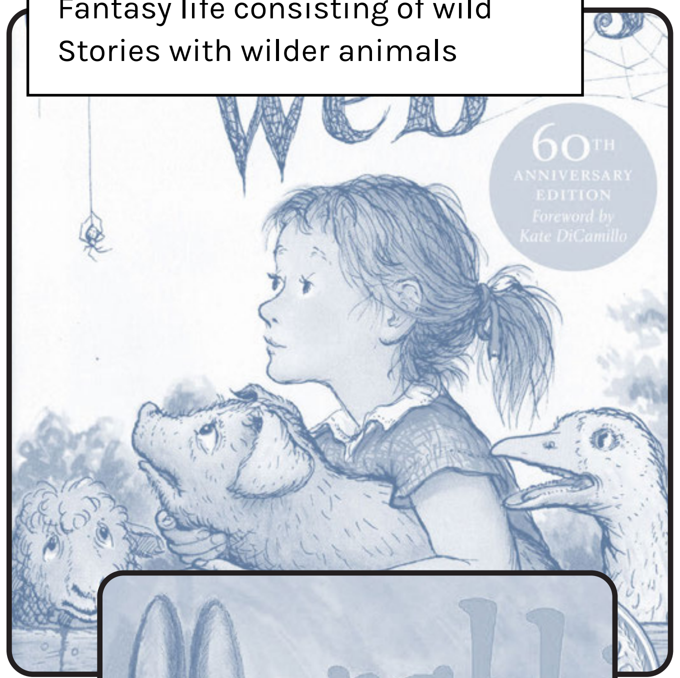
Concept storyboards were used as a stimuli to envision the desired interaction of the concept.

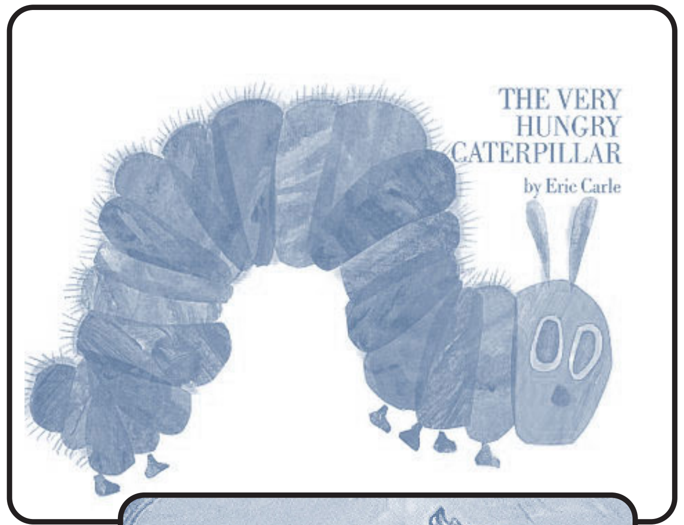
The storyboard was used as a guide for narrative transportation to get feedback from the stakeholders involved. In this way, refinements were made to the earlier storyboards based on the discussions to define the scope and to come up with the current version as shown here.

Storytelling is fundamental for children of age 4 to 7 years

Hastings Storytelling Festival

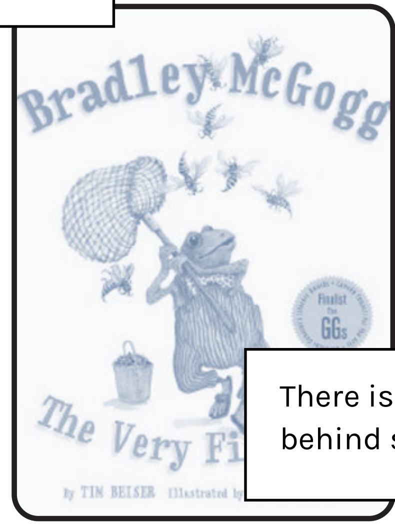
As children, we had an amazing Fantasy life consisting of wild Stories with wilder animals

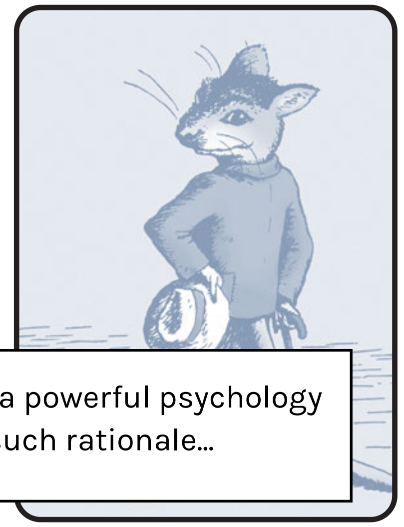




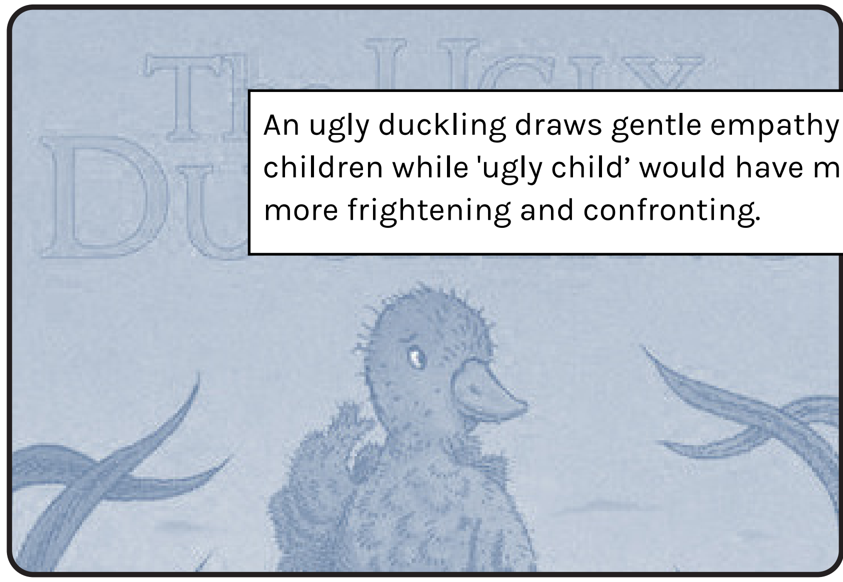
Our imagination used to run into a different trajectory

Animals are often used to create powerful storylines for children





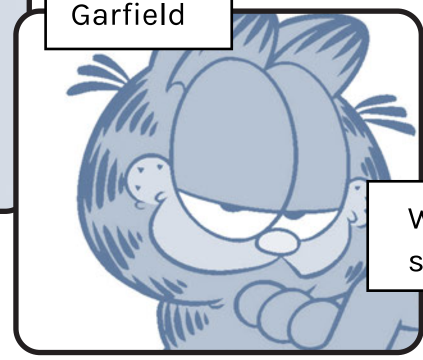
There is a powerful psychology behind such rationale...



An ugly duckling draws gentle empathy from children while 'ugly child' would have made it more frightening and confronting.

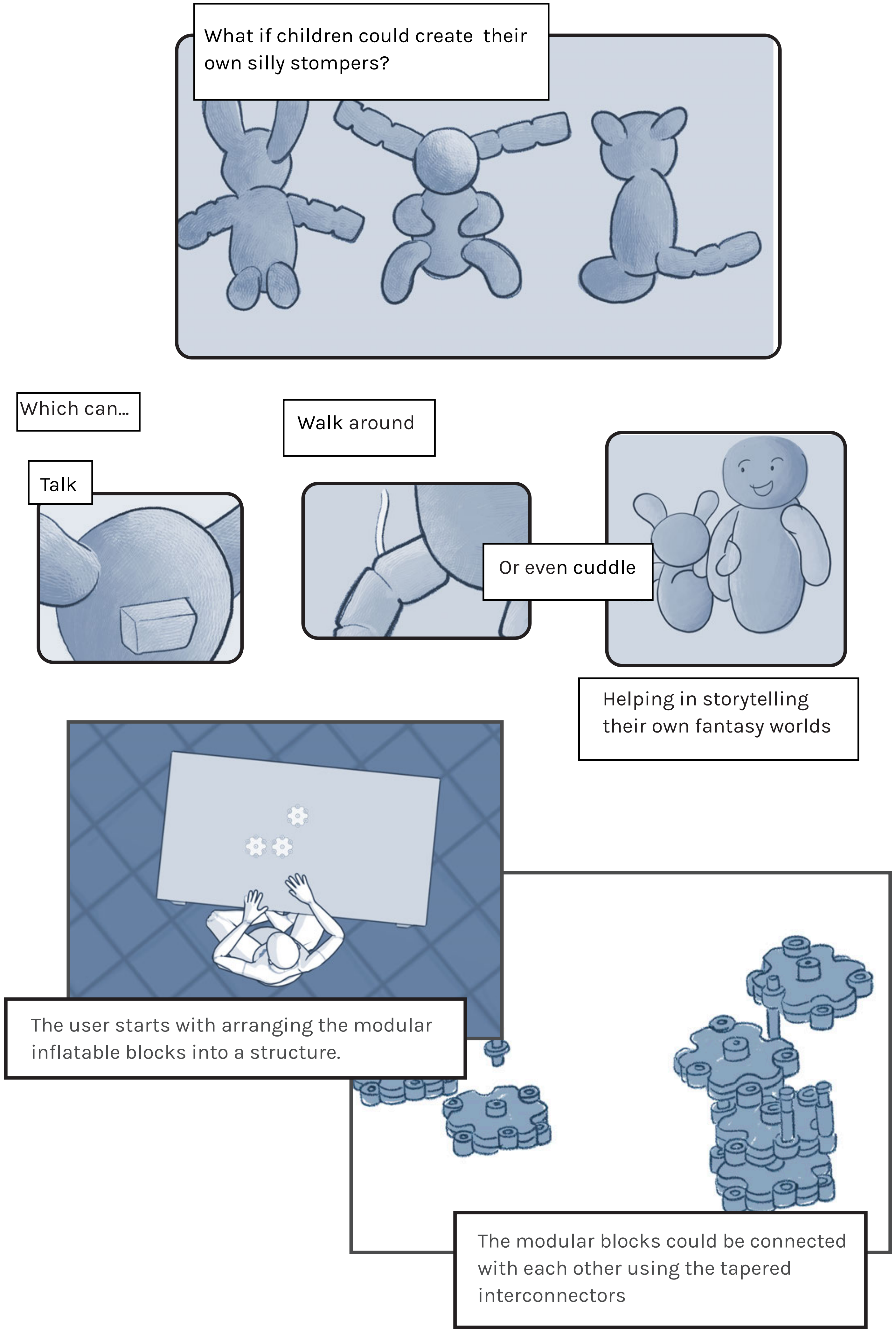
Courage the cowardly dog

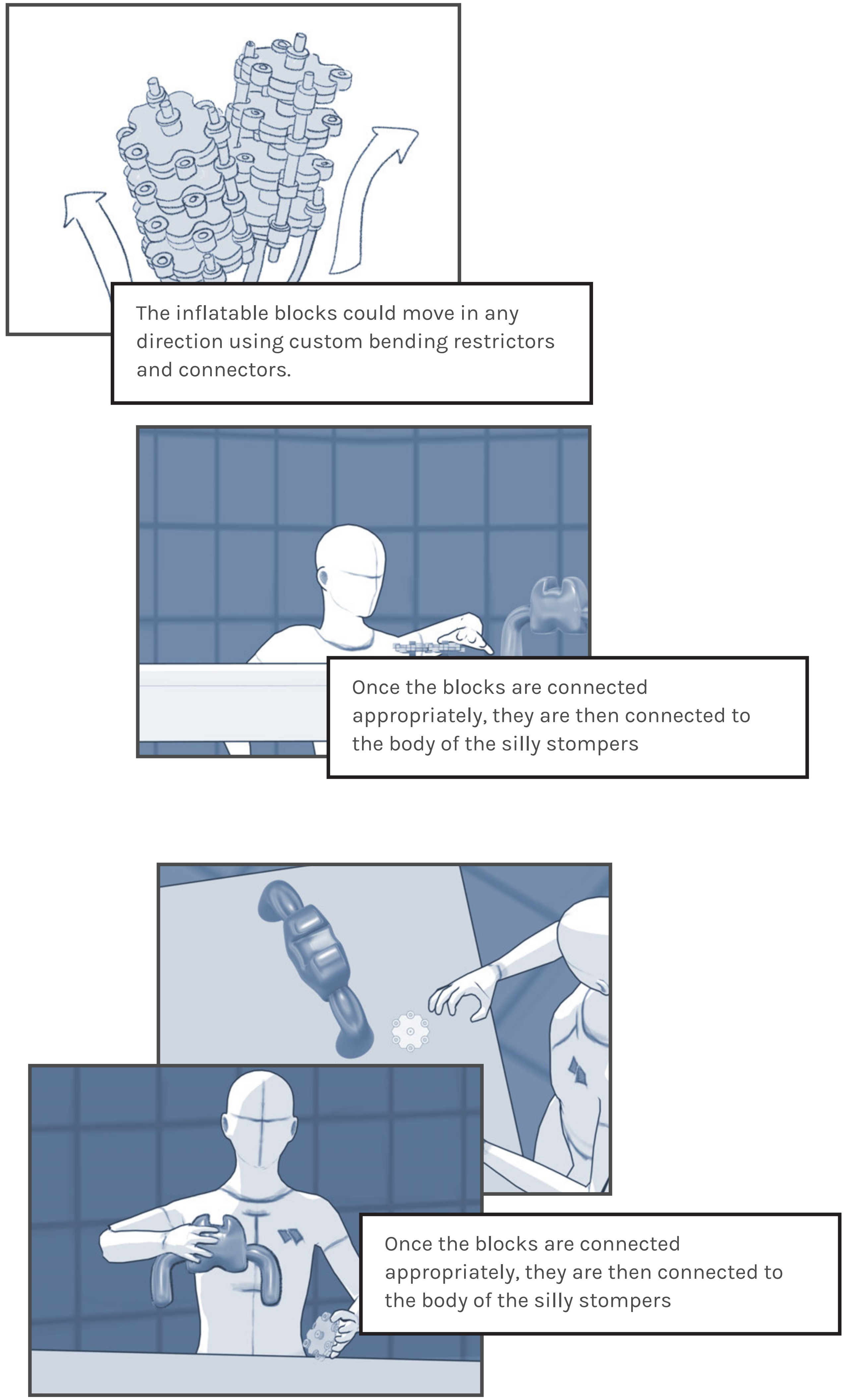
Garfield

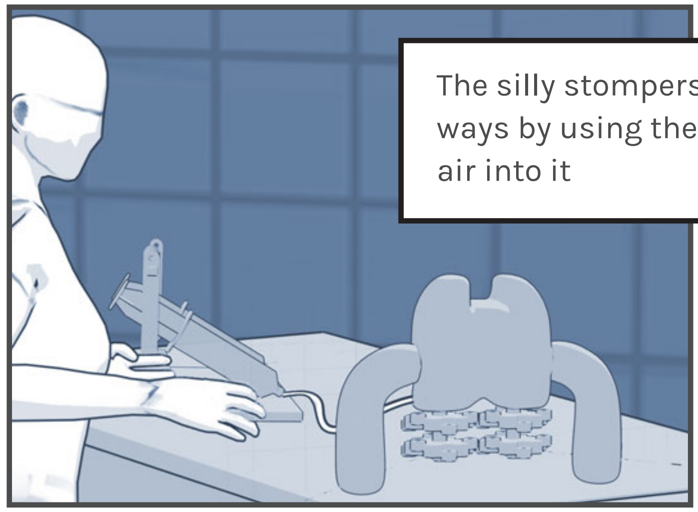


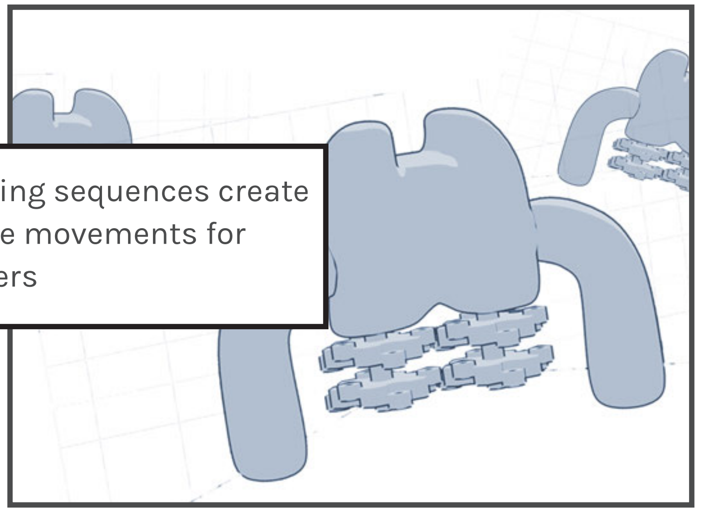
Pooh

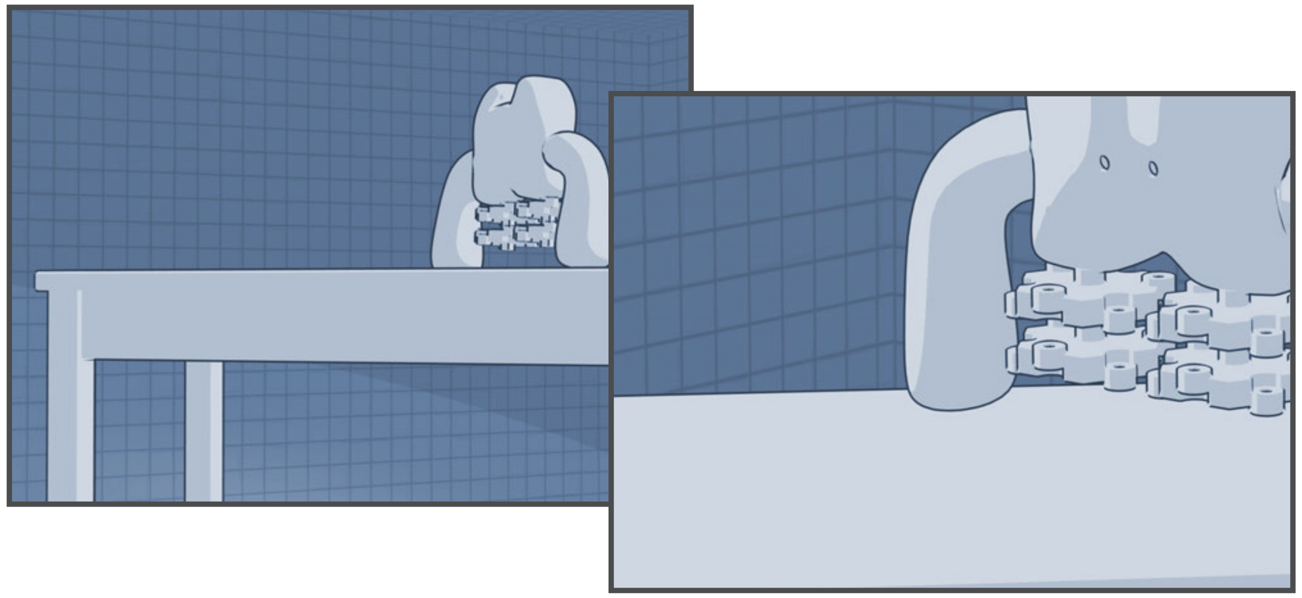
We could see countless such examples..

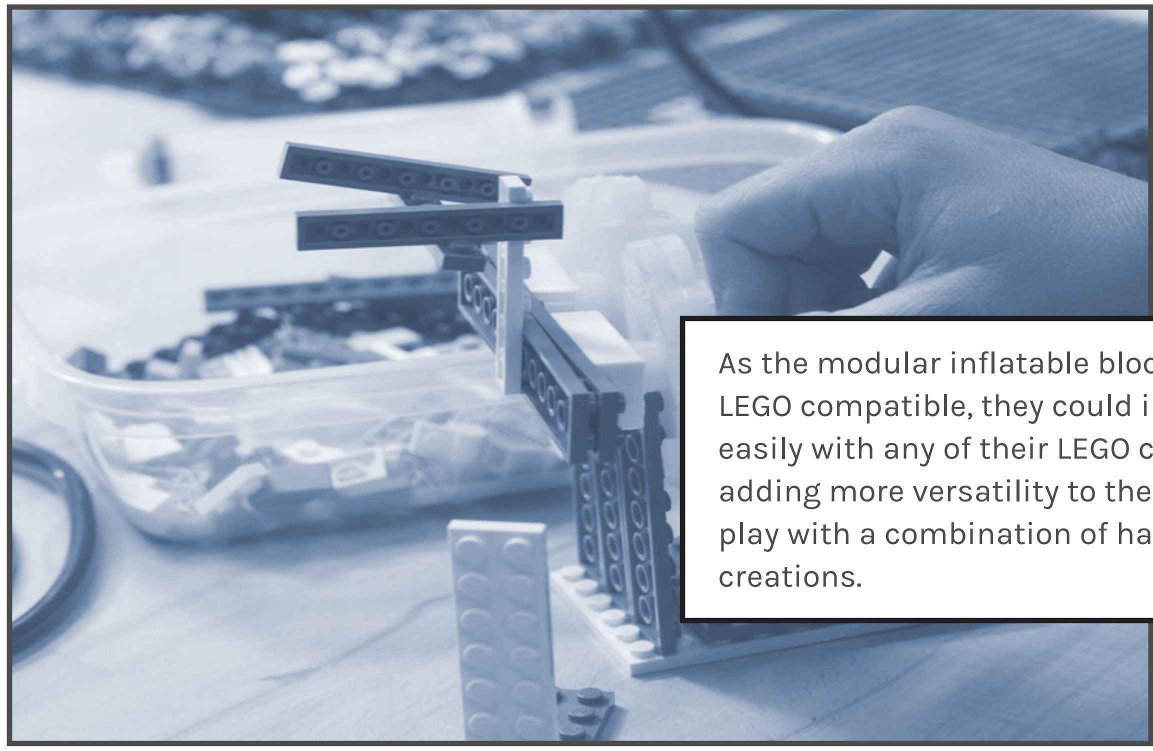

What if children could create their own silly stompers?
Which can...
Talk
Walk around
Or even cuddle
Helping in storytelling their own fantasy worlds
The user starts with arranging the modular inflatable blocks into a structure.
The modular blocks could be connected with each other using the tapered interconnectors

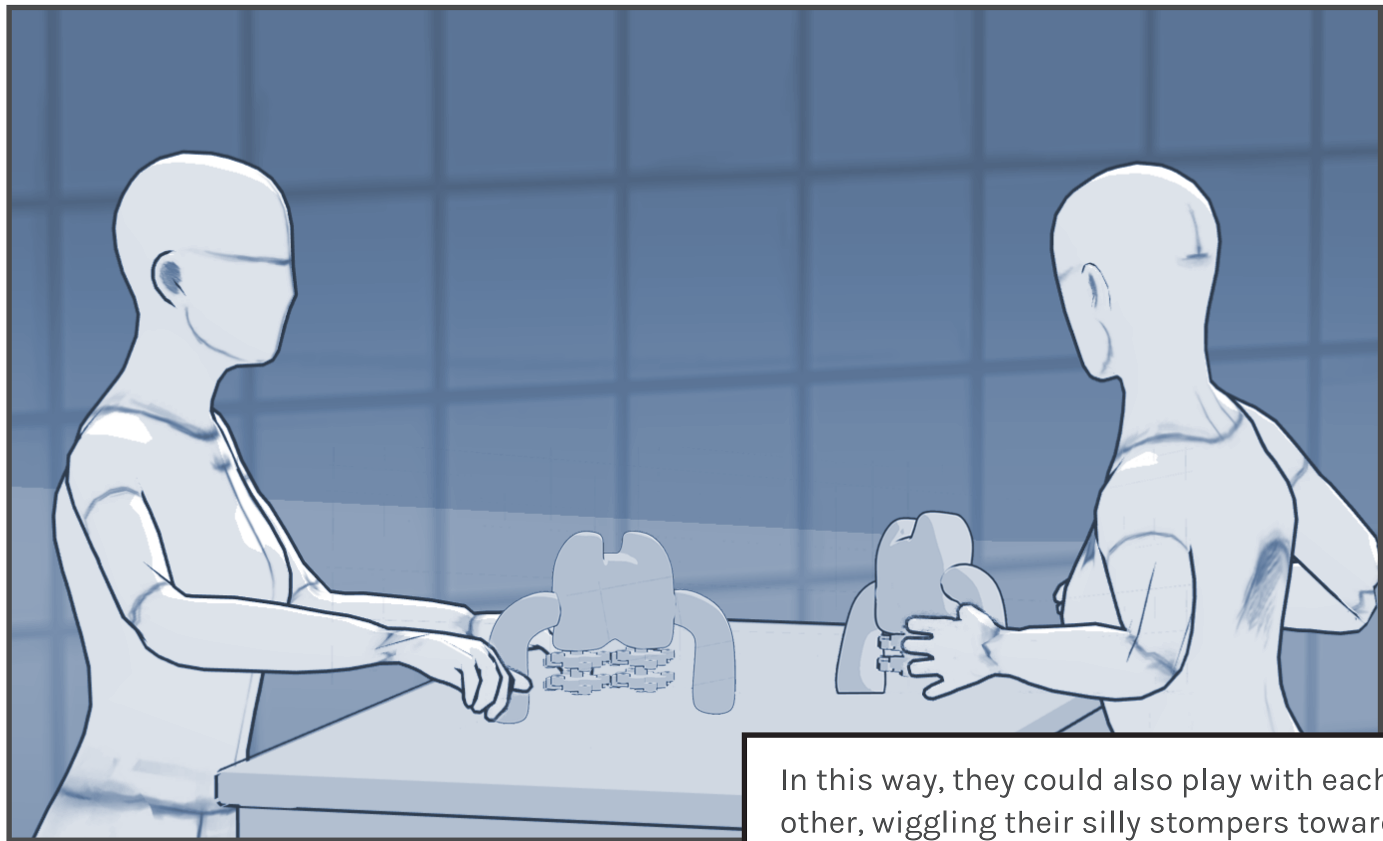

The inflatable blocks could move in any direction using custom bending restrictors and connectors.
Once the blocks are connected appropriately, they are then connected to the body of the silly stompers
Once the blocks are connected appropriately, they are then connected to the body of the silly stompers


The silly stompers can walk in different ways by using the syringe system to pump air into it


Different pumping sequences create different wriggle movements for the silly stompers



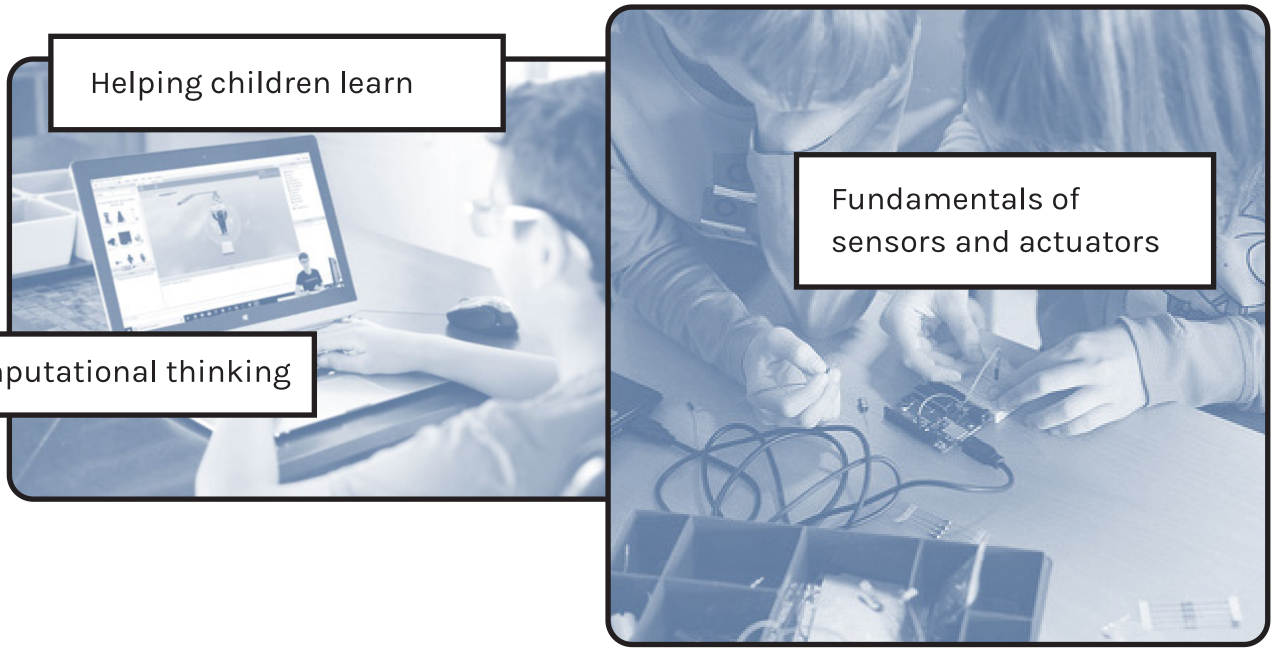

As the modular inflatable blocks are LEGO compatible, they could integrate easily with any of their LEGO creations adding more versatility to their open ended play with a combination of hard and soft creations.


In this way, they could also play with each other, wiggling their silly stompers towards each other, or even dancing together if they'd like. Pumping air in various ways make it more engaging for the children to create custom body motions.

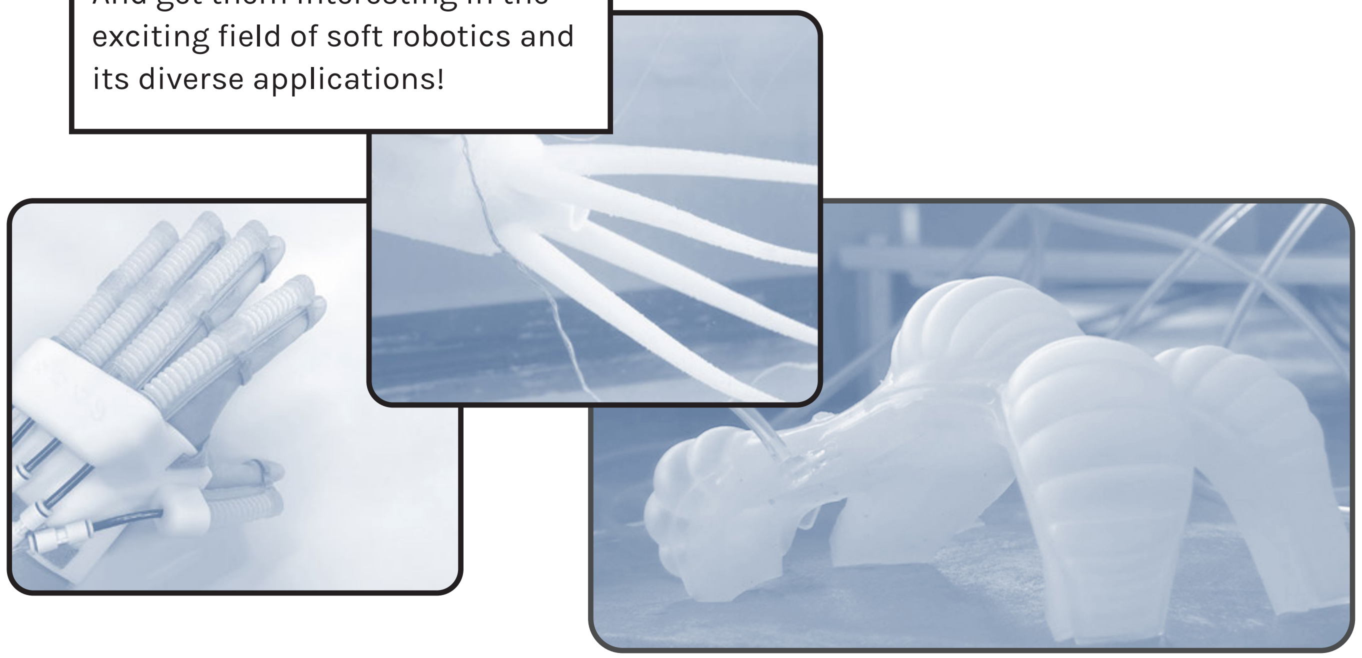
Helping children learn

Fundamentals of sensors and actuators

Computational thinking



And get them interesting in the exciting field of soft robotics and its diverse applications!

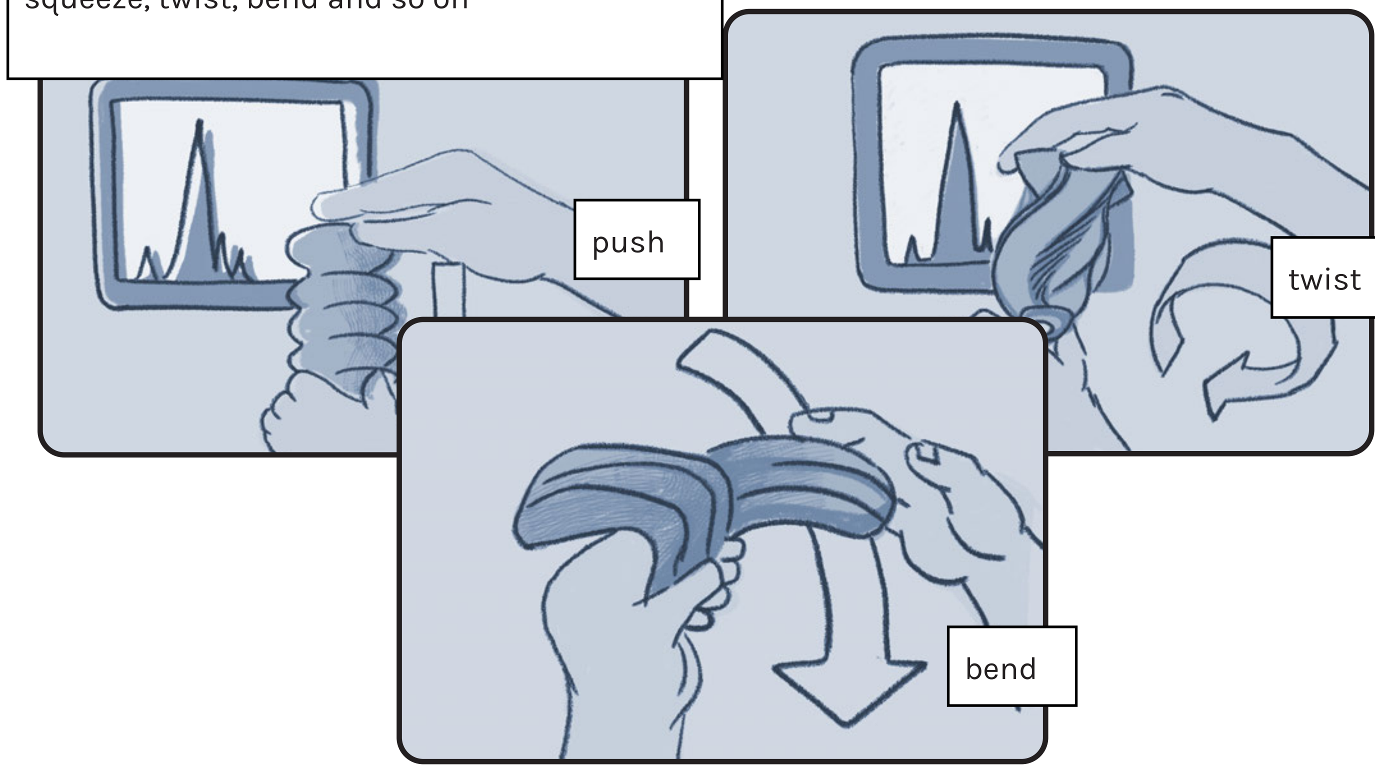


3.2.2

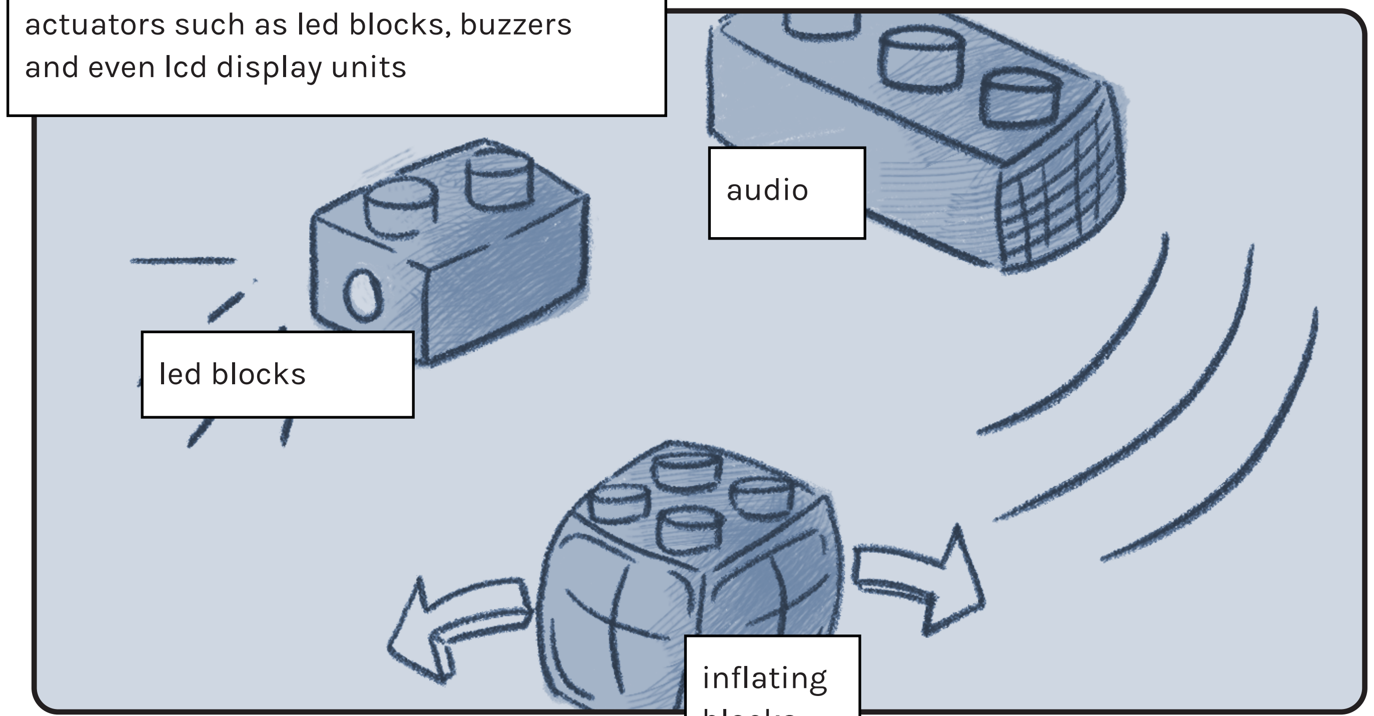
future interaction

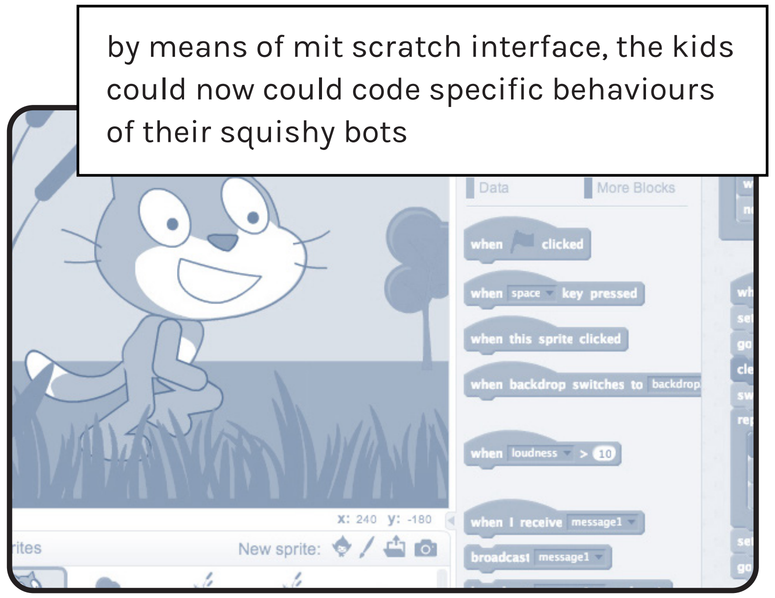
children could also start plugging in various sensors and actuators to create various gestures and interactions

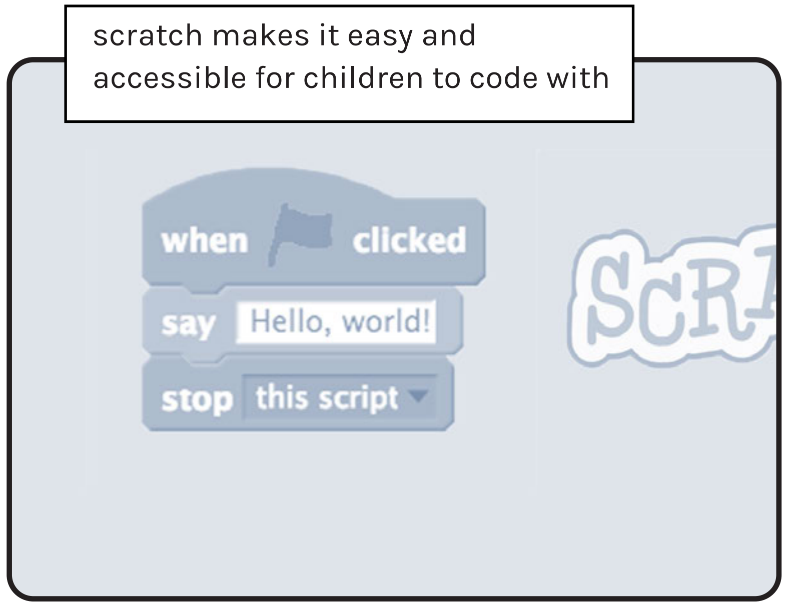
as sensors, they could connect various touch based interactions which detect push, squeeze, twist, bend and so on

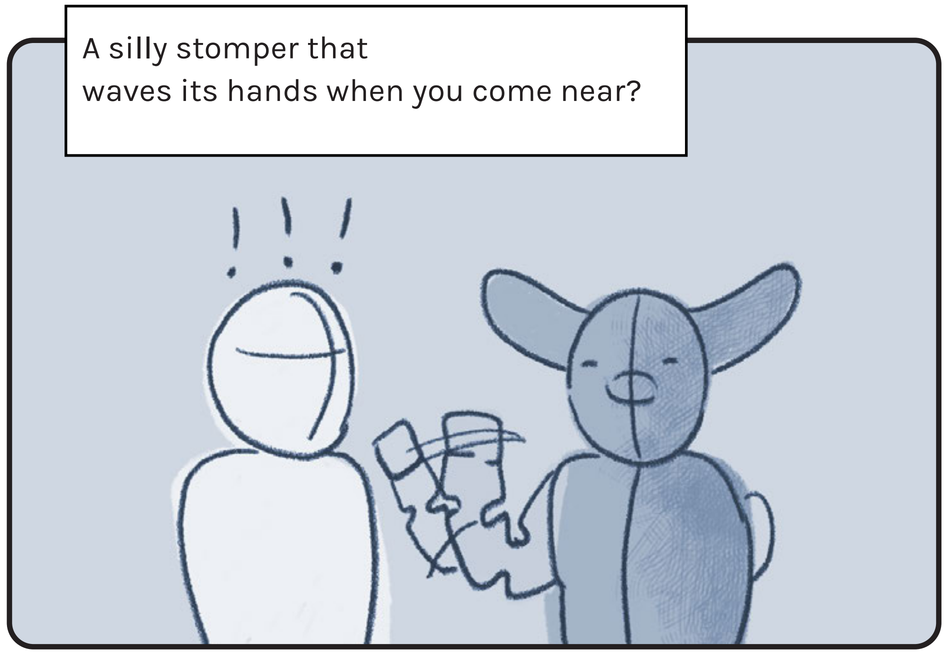


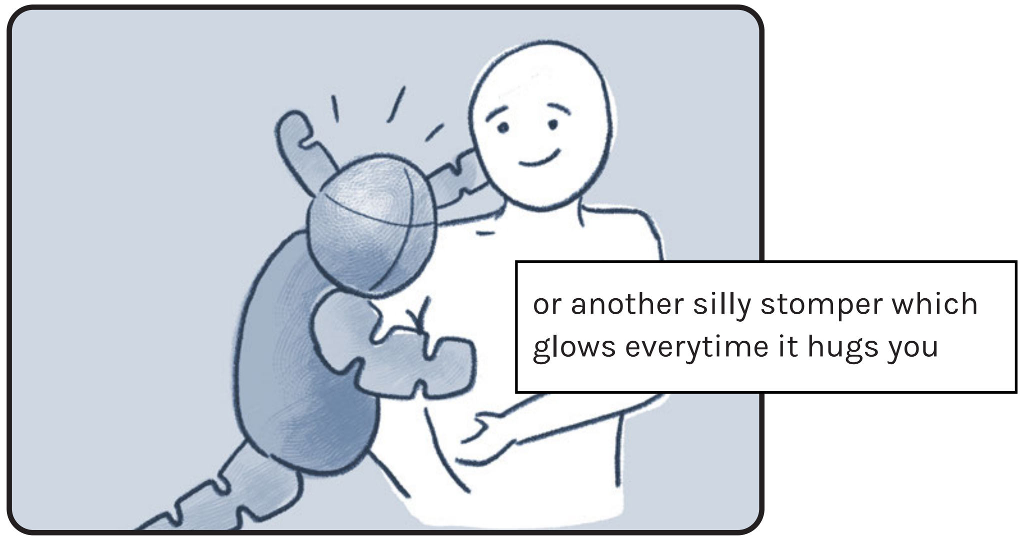
and can connect to various other lego like actuators such as led blocks, buzzers and even lcd display units

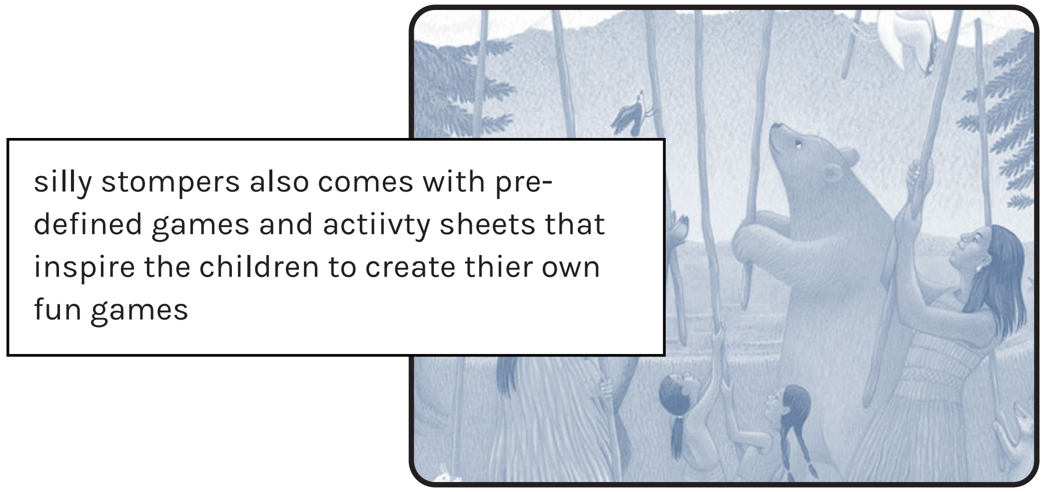


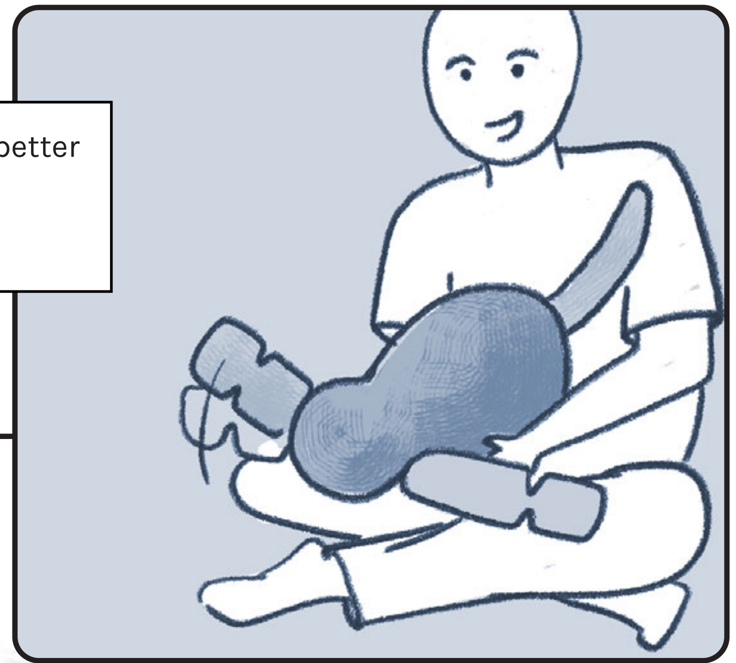

by means of mit scratch interface, the kids could now could code specific behaviours of their squishy bots


scratch makes it easy and accessible for children to code with
when clicked
say Hello, world!
stop this script


A silly stomper that
waves its hands when you come near?


or another silly stomper which glows everytime it hugs you


silly stompers also comes with pre-defined games and actiivty sheets that inspire the children to create thier own fun games


helping children imagine better and to create stories with their sily stompers

form and experience

3.3.1

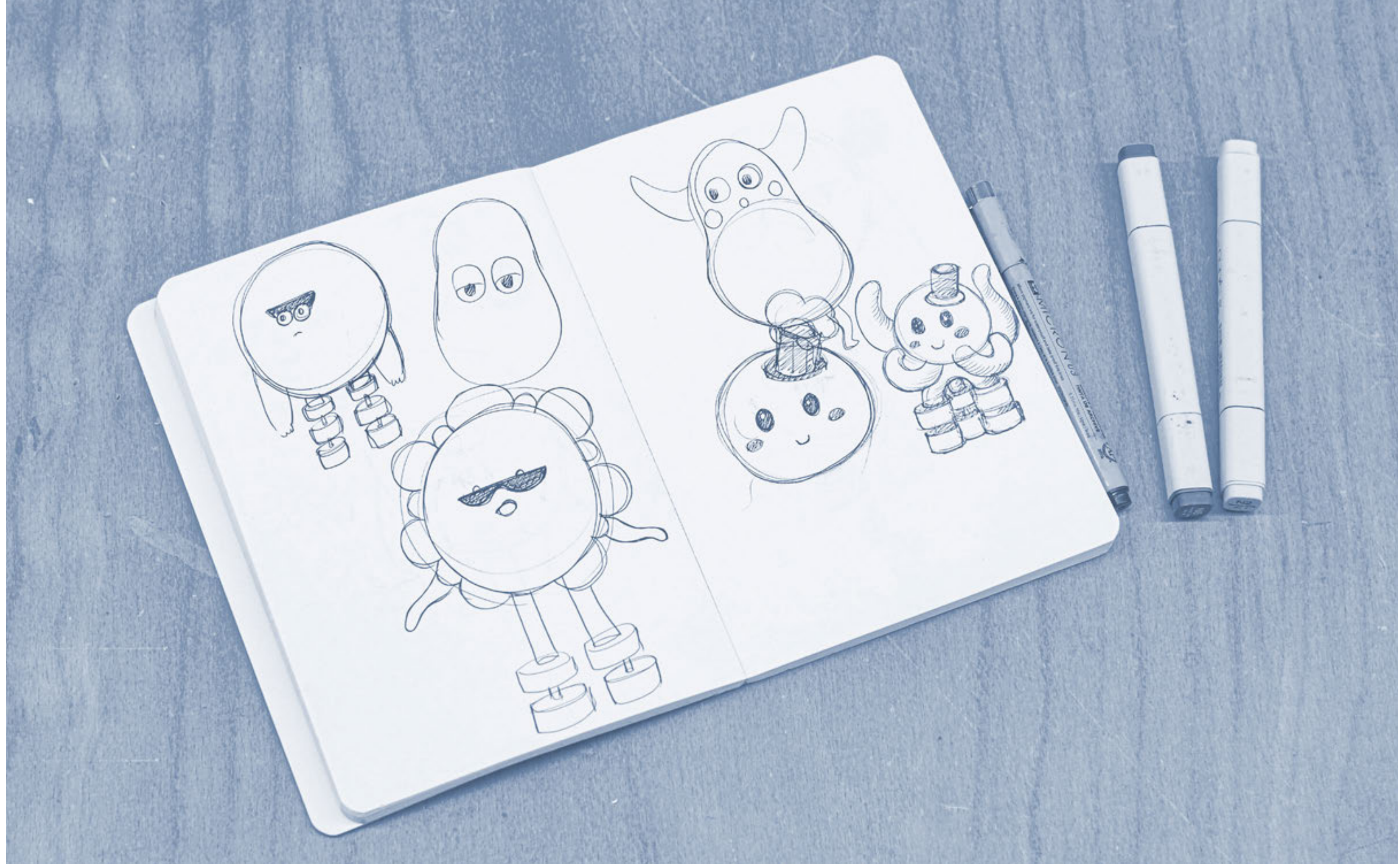
Form and experience plays a pivotal role in this project as the experience delivered through the toy should relate well with the age group of children and should inspire them to storytell and roleplay.

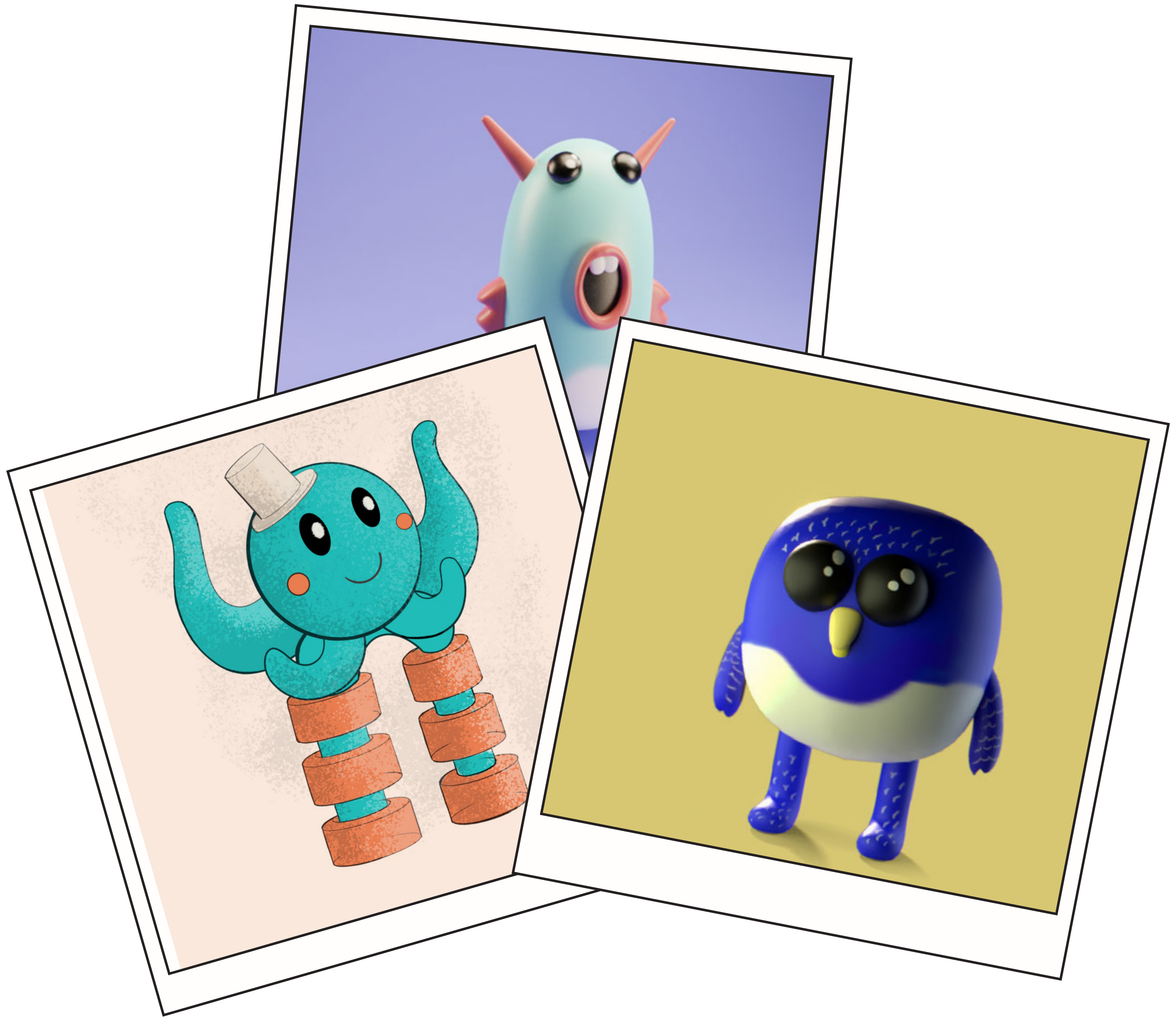
A 7-year-old is probably excited by flying a pretend spaceship around the room, but they probably aren't that interested in a scale model of Big Ben, or a model of a retro Volkswagen Beetle. The subject matter of a set is a large component for who the set is aimed at and that requires careful consideration.

9 Moments of Product Experience (Appendix B.2) is used as a framework to chart out the experience qualities which are then mapped with the product qualities. This is followed by moodboards on emotions and gestures, morphological chart on the types of body movements to arrive at a primitive form. This is then run through Sam de Visser's six main aesthetic features such as Balance, Movement, Repetition and Rhythm, Emphasis, Simplicity, Contrast, Proportion, Space and Unity.

Along with these aesthetic aspects, two other aspects are taken into account while designing the form of Silly Stompers - The stability of the body not falling down, but also making sure that it could be pushed or thwarted forward by means of the soft modular blocks.

Apart from this, the other aspects taken into account is the functionality of open ended play.

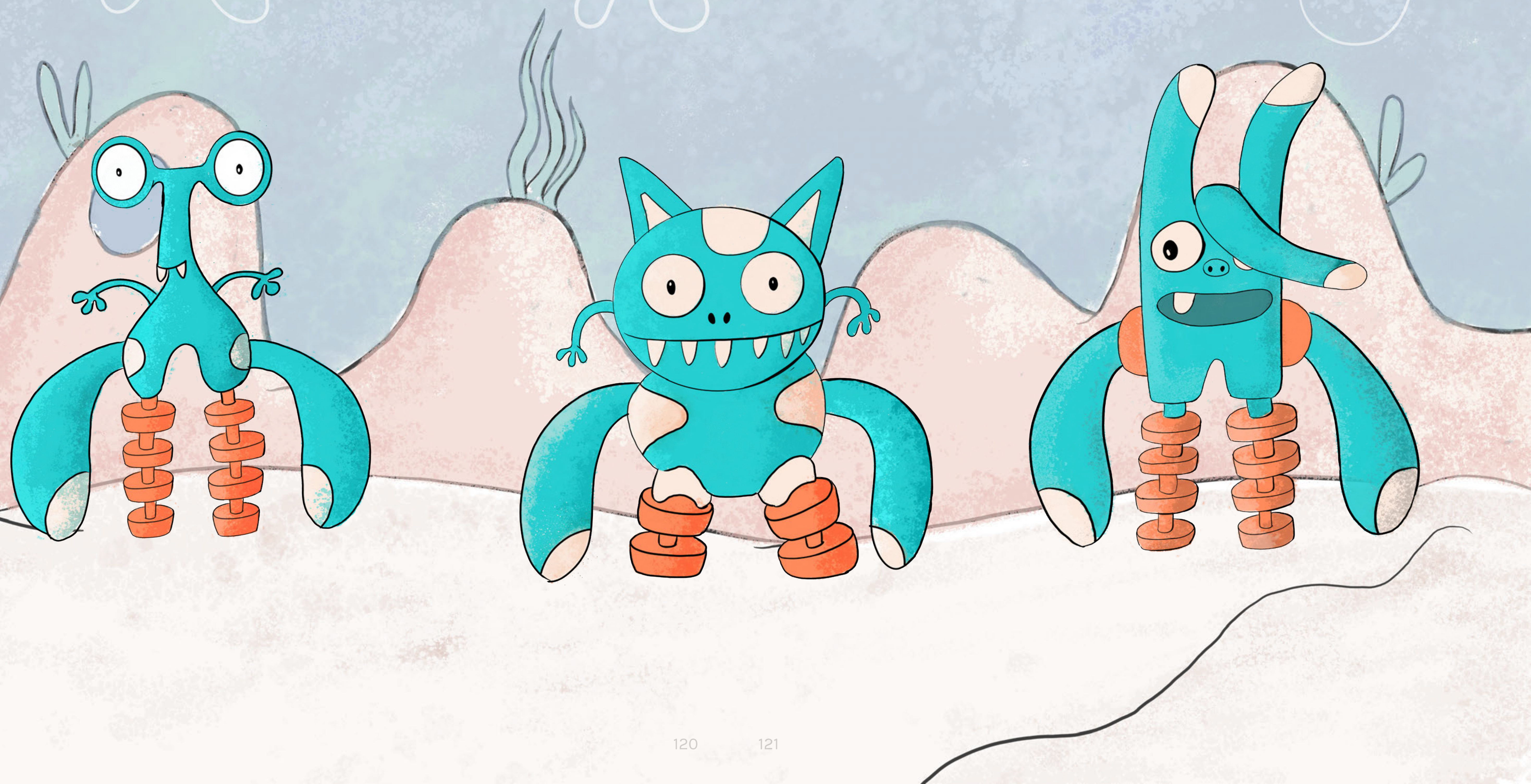




silly stompers

According to (R03, R11, R15), an ideal combination of roleplay with constructivist play makes for an interesting play based learning experience for kids of this age group.

The story of the Silly Stompers revolves around the ocean bed with these three characters who are busy carrying out their day to day activites as they stomp their way through the ocean bed.



3.3.3 learning outcomes

Evaluating the final concept based on the 8 pedagogical principles for the learning outcomes (Chapter 1.8.6)

active learning Defines the cognitive, emotional and behavioural activity for better student engagement	Through roleplay and storytelling, the experience becomes much more active.
collaborative learning Approaches designed to maximise positive peer interactions through thoughtfully structured group	Children could combine in teams to play their characters and perform various desired body movements.
experiential learning Notion that quality experiences within and beyond the classroom promote meaningful learning	
guided discovery learning 'to expect and be prepared to discover knowledge' with the support and scaffolding of a teacher	Based on scaffolding (Gelderblom, 2008) to use the stomping nature of the characters for guided learning and then introduce them to more complex motions by interfacing with LEGO
inquiry based learning Involves organising a unit of work around relevant authentic, open-ended questions	
problem based learning Involves structuring an integrative learning unit around a problem. The richness of the vehicle acts as a problem.	Customising the motion of the animal involves customising the bending restrictors, fixed restrictors and the modular soft blocks
project based learning Projects as vehicle for delivering the curricula.	Locomotion as a media for active project based learning

3.3.4 the gender equation

Apart from the learning outcome based evaluation, while considering the key concept driver of gender-accessibility, this was determined based on the 4 design tests conducted (Appendix A) wherein 9 participants (4 male, 5 female) were involved.

The research through design approach provided step by step feedback on whether the embodiment and the function was equally received by both the genders or not.

From the graph shown here Fig. 3.3.4, PlaTUI tool was used for evaluating the likeability of play itself using simple questions and answers. Out of 9 male participants, 4 of them wanted to play with the product again. And out of 5 female participants, 3 of them wanted to play with the product again. Although the size of the sample is uncertain to make a judgement, the observational studies and expert opinion went hand in hand to make sure that gender-accessibility was addressed through design.

Although storytelling was an important element of the whole user experience as per **R03, R11, R15**, it was not within the scope of the project to detail the embodiment. Therefore, the aspects of color and form based experience were not separately evaluated. What was evaluated was the experience of soft and materail objects and the whole inflation experience in itself.

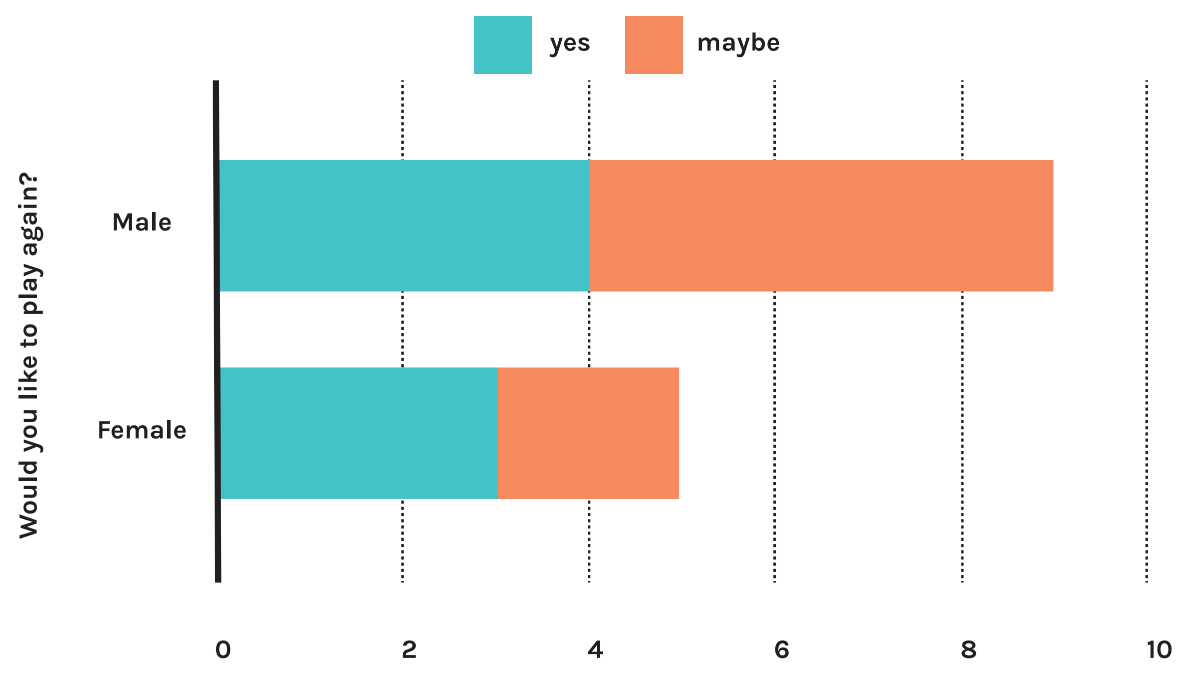


Fig. (3.3.4) Distribution of PLATUi scores for boy and girl participants as per Appendix A

embodiment challenges

3.4.1

As shown in Fig. 3.4.1, there are three major subsystems for the product namely (syringe pumping unit) (silly stompers) and their limbs (consisting of modular inflatable blocks) as shown. The listed embodiment challenges are solved one by one through project planning.

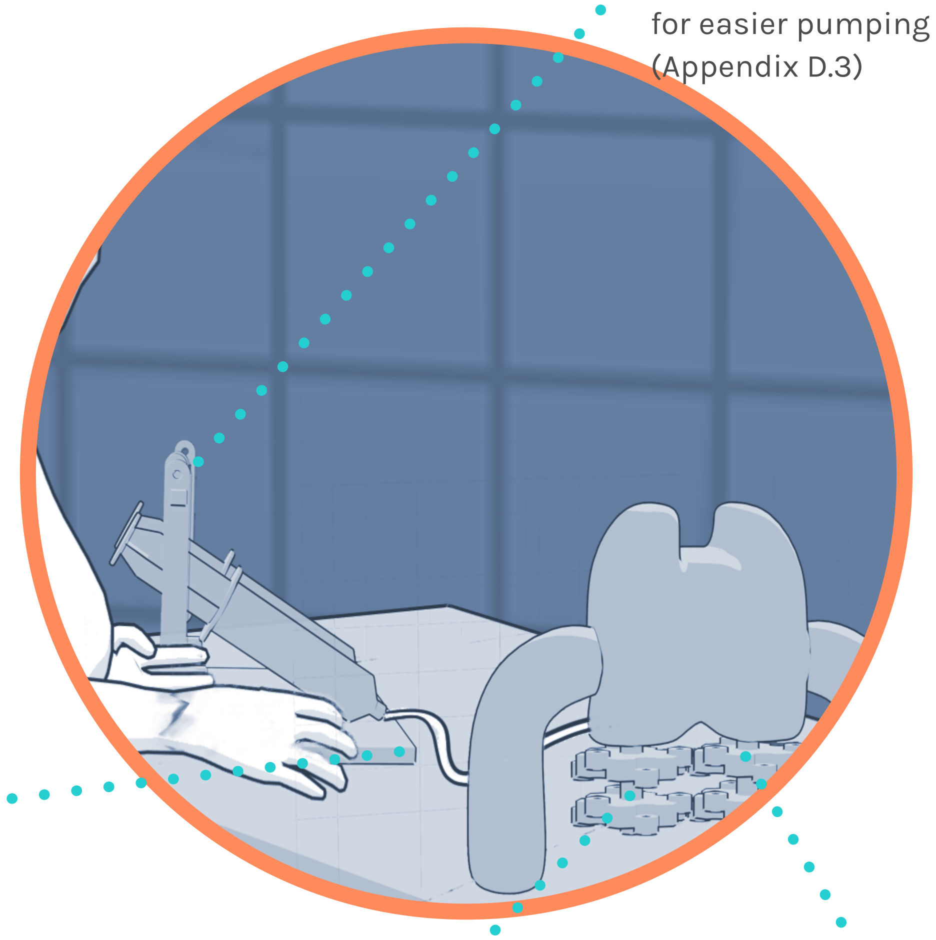


Fig. (3.4.1) Key embodiment challenges listed in detail for the product

viability

3.5.1

market size

The aim for the first two years is to target parents from middle to high income households from EU, for which the Total Addressable Market(TAM) is around 10.78 million, and the Serviceable Obtainable Market (SOM) is 430,000.

With the product priced at 150 eur, the total revenue of 64mn can be targeted, spread across five years. We plan to expand to the US and UK markets after the third year since these markets already have interested customers for the coding toys, as shown by the Google trend analysis.

Silly Stompers could cater to the audience focussed on screen free coding experience in a gender-accessible manner. Although at present, the product doesn't have coding functionalities, it acts as a launchpad to create various cause-and-effect relationships using sensors and actuators.

With an additional SOM of 335,000, it opens up an opportunity to get additional revenue of 50mn euros spread across next 3 years.

beachhead market

Netherlands has the fastest growing toy market in Western Europe which showed a growth of 3 percent in 2017 (Ofcom, 2011)

scalability

As per Google Trend analysis, STEM toys for children are most trending in UK, Finland, Australia, Canada and the United States. Finland is a nice proposition for the first stage with Finnish schools as early adopters, and then the rest of EU and UK as the follow up markets.

channels and touchpoints

online retail

Since the number of physical retail stores is declining by more than half (ABN Amro, 2018) and also due to the current rise of e-Commerce with regards to COVID, more customers are preferring to buy toys and educational materials online. Hence, our main channel would be e-Commerce. This also cuts down costs on logistics and warehousing.

experience spaces

According to the market research, in order to penetrate the schools as a Decision Making Unit, it is usually the teachers who don't prefer to try new brands and teaching approaches. Hence, to reach school going students, playspaces such as makerspaces, hackerspaces (Ontdekfabriek, NEMO etc), LEGO playspaces and libraries can be approached. The goal is to provide experience of Silly Stompers to these children, and also to maximise product visibility to parents.

customers

Although end users are children (aged 4-7 years) - 620k kids in the Netherlands for the beachhead market, the economic buyer is specifically targeted towards middle to high income parents.

competitors/substitutes

Although there are no specific toys introducing soft robotics as such, there are various substitutes in the form of tactile programming toys such as Cubetto, TACO Playbits and Cubroid, Ozo bot, Sphero, Makeblock Neuron. However, Silly Stompers stands out from the competitors for mainly two reasons: It encourages kinesthetic play involving more children to play in a collaborative team. The product has a potential to be compatible with the competitors' and the substitutes' toys, making them as an opportunity rather than a threat to the product.

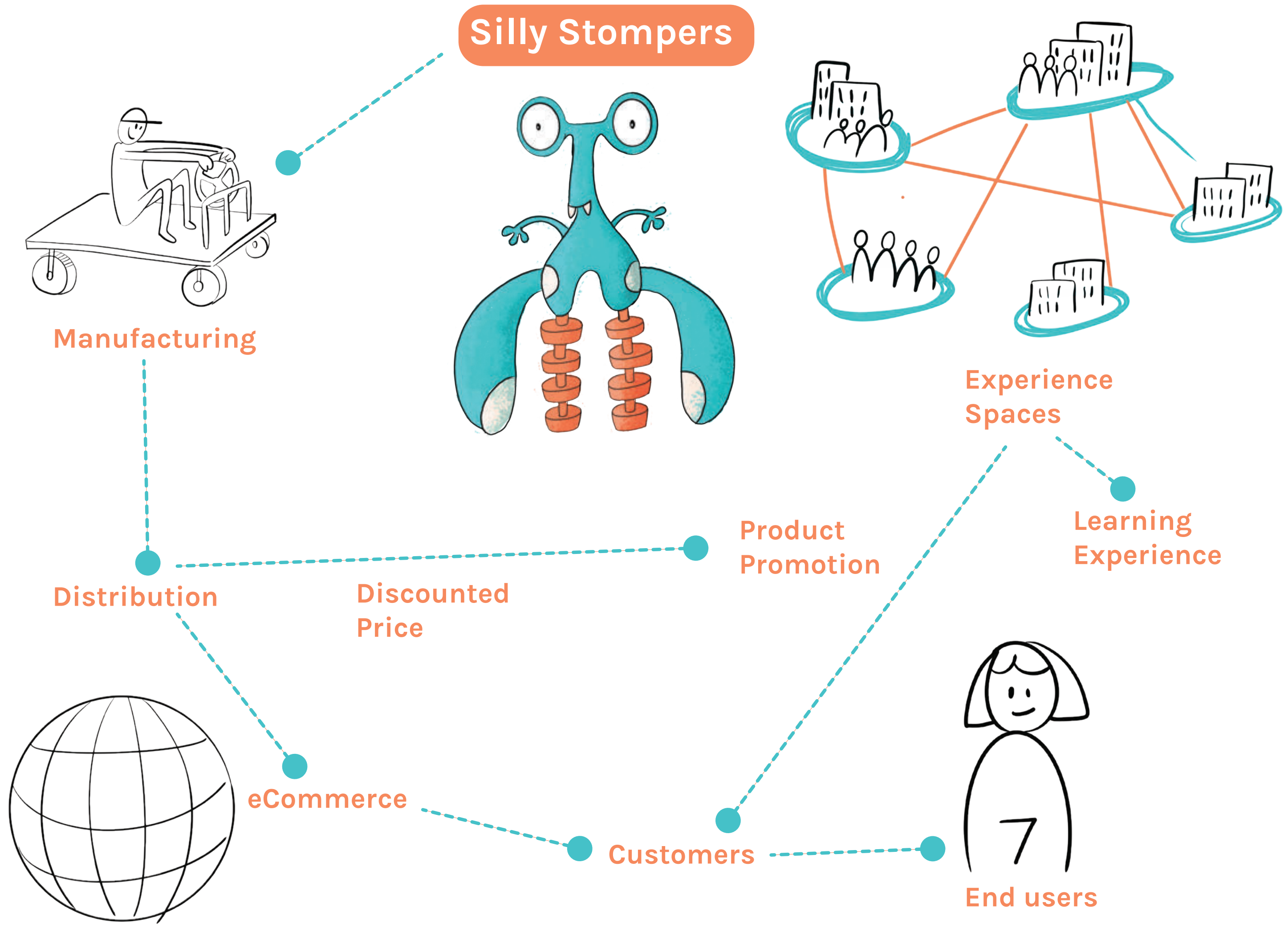
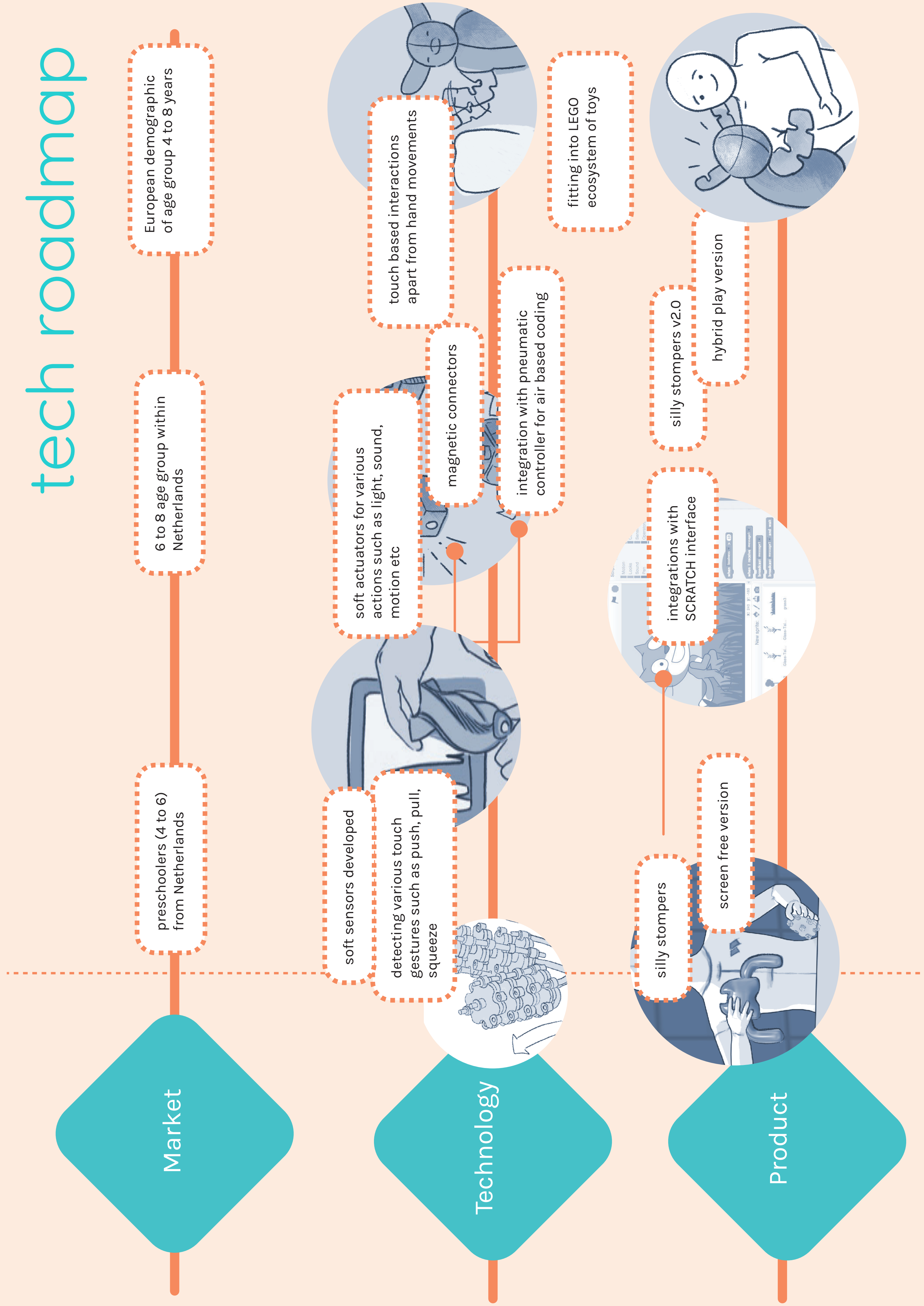


Fig. (3.4.1) Distribution strategy for Silly Stompers



3.5.2
tech roadmap

As the trends slowly progress towards various forms of digital and physical construction kits, an adoption of Blended learning could play as an interesting proposition to engage in both the physical as well as the virtual at the same time - an interplay between the two (Hanning, 2016)

SCRATCH, a visual programming language developed by the Lifelong Kindergarten of MIT Media Lab has made digital play much more versatile and easier for kids to engage with. Over the time, SCRATCH has seen various extensions developed for connecting the SCRATCH programming language to the physical world.

For instance, with regards to the LEGO WeDo kit, it is being commonly used to teach robotics for younger kids of age 4-7 with a range of light and tilt sensors, and a motor for making physical connections which are also seamlessly integrating with SCRATCH.

As there have been various such experimental additions through the medium of SCRATCHX which is facilitating this crossover, a SCRATCH extension for Silly Stompers could provide the Blended learning interplay. This could serve two key advantages for Silly Stompers - Instead of designing sensors and actuators from scratch, it could potentially hop onto the existing ecosystem of SCRATCH dependent physical extensions such as ScratchBit that can provide seamless integration with Scratch programming environment.

Based on the figure (3.5.1), there could be various touch-based interactions of Silly Stompers themselves that could be helpful in creating a wide variety of animated expressions. Essentially, the Silly Stompers are brought back to life by coding the required responses for human-robot interactions through playful gestures as shown.

Silly Stompers could act as ‘wonderful objects’ (Hanning, 2016) which could provide the foundation for participants to explore their own ideas and engage in meaningful and open ended play.

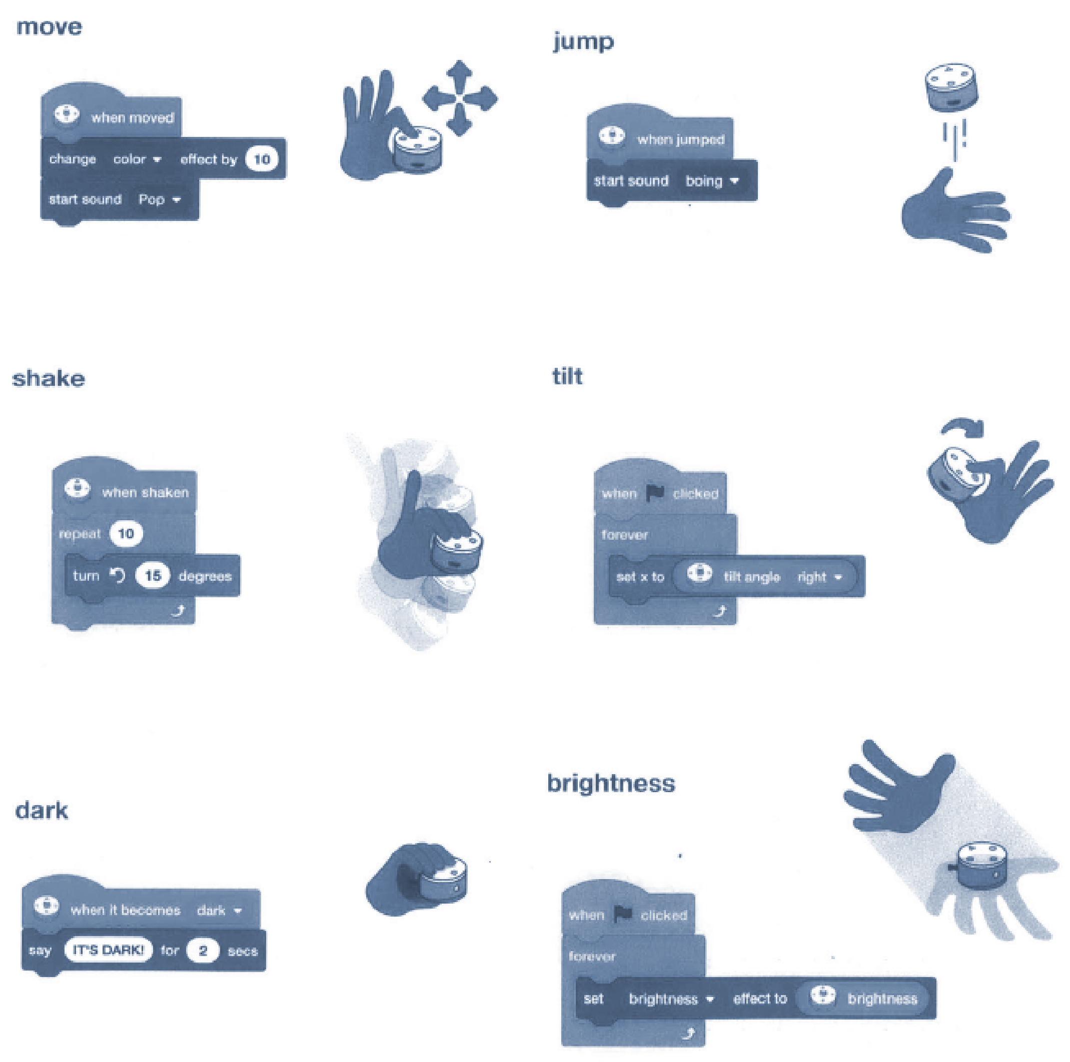


Fig. (3.5.2) Scratchbit mini-card examples showing home custom gestures of the blended learning object could be encoded

As shown in the current stage of concept development, the product involves actuation systems by means of syringes which can go up and down by means of a lever mechanism. At a later stage of product development, this could help children create logic loops and action sequences which can be automated. In this way, they learn basics of programming by means of pumping air.

In the future scope of development, it could be interfaced with SCRATCH which could help expand the capabilities of using this toy. Currently, by means of LEGO connectors, it already has LEGO compatibility which can be extended to LEGO's wide range of sensors and actuators through the SCRATCH interface.

3.5.3

recap of embody phase

In the final phase of the embodiment in itself, narrative transportation (Chapter 3.2.1) and probing are done through various prototypes as a form of enquiry.

In this phase, the evolution of the prototype with respect to clearing the assumptions is achieved. Through validation by means of design tests, a series of objectives are tested leading to further feedback towards to the design of the product itself.

The phase culminates through the showcase of the final validation (Chapter 3.1.7), an interaction storyboard, and the final embodiment depiction along with how it leads to gender accessibility (Chapter 3.3.4) and learning outcomes. (Chapter 3.3.3) recommendations

3.6.1

sensors and actuators

A significant phase of the project was in demonstrating a proof of concept of how the soft sensors could be integrated onto the body of the toy. Three different types of soft pressure sensors which detect press, squeeze and twist were designed according to (Appendix D.6). This was however not realised completely and is pushed further down the timeline to illustrate the future roadmap. The sensors could potentially also include haptic feedback for helping children understand the gestures faster. For the light-based sensors, they could be embedded into the body of the silicone materials giving rise to illumination in various colors.

In 6-12 months, the sensors and actuators developed could be integrated with what is currently available, helping children to learn coding along with integrating the wide variety of applications of soft robotics.

integration with SCRATCH

The sensors and actuators system could be integrated with SCRATCH for helping them code the required responses and to create their own logic. SCRATCH provides extensive documentation for developers to create plugins for custom sensors and actuators which have been designed. Not just that, it also provides extensions for LEGO WeDo and other robotics kits, indicating potential to combine later on as a LEGO extension.

animal body movements

In the current phase of development as shown in (Chapter 3.1.7), two-limb body motion is achieved using two connection points for limbs. In the future, various custom animals could be designed with different ways of locomotion. For instance, in this paper by (Yu. et. al 2013), locomotion was illustrated as a workshop for younger kids, indicating potential to create custom body variants which includes the motion of say, a caterpillar, snake and other wiggly motions.

recommendations

3.6.1

interconnectors for soft actuators

Although the decision was taken to go ahead with the tapered conical connector for the inflatable modular blocks, the magnetic connectors were also a plausible solution. However, the magnetic connectors were not molded adequately because of the sizing errors which resulted in air-leakage. (Appendix D.4) Although magnetic interconnectors have been realised by (Kwok. et. al 2014), the combination of these plug-and-play type connectors and their potentiality to combine with the LEGO exosystem has not been explored so far.

soft robotics workshops

Workshops could be conducted using this soft robotics set. For making it more engaging, there could be storybooks which go along with these and help them create the desired roleplay. Onomatopoeia could be used as a prompt to create custom body movements. (Seong. et. al 2014) references

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appendix A

tests and observations

A.1 design test 1

goal

How enjoyable is Soft InflatiBits as compared to the rigid InflatiBits and to discover if fun and interactivity are related

research question

To determine the enjoyability of Stimuli A and to observe the differences in enjoyability of Stimuli B.

What is the perception of silicone material during the interaction?

Variables to be observed:

V1a) Attention: Is oriented towards the toy
V1b) Attention: Is attracted by visual stimuli

introduction to research

Method
In total three participants will participate in this study. All the three participants are members of the De Bouw Bonteplaats, a LEGO Playspace and are chosen in consultation with the educator. The signed consent forms can be found in the Appendix

Inclusion criteria
Children of age 4 to 7
Informed consent from parents
Member of De Bonte Bouwplaats

Exclusion criteria
Bedridden/ not participating in any activities
Materials required for the test
Pen, Paper for the PLATUI sheet
Observation guide sheets

Guiding questions for the facilitator (post test interview)

Stopclock

object and stimuli

For this test, two kinds of touch based stimuli (A and B) are used to attract the attention of the participants involved consisting of rigid, and soft touch. In addition to this, a formative evaluation is carried out to understand the interesting aspects of the stimuli.

Instructions in advance (which would be explained by the facilitator)

Stack the rigid blocks into one combined structure that stands
Inflate the combination of soft blocks together.

environment and test setup

The participants are seated across the table with the stimuli objects placed in front of them (A and B). Two roles are assigned amongst the researchers. One moderator, and one observer. A professional facilitator is present during the test.

The test takes place in the activity area of De Bonte Bouwplaats. The observer takes an unobtrusive position in the room, as much away from the children and the setup as possible, also maintaining a proper distance. The environment is set up for one participant at a time. Six minutes of time is given for the completion of each task

test protocol

To minimise the disturbance, the observer takes place in the room first. After a few minutes, when the participant has no attention for the observer anymore, the moderator places the object in front of the table, without giving any explanation.

When the test starts, the first stimuli A is given and a design challenge is given to them. While this is carried out, the observer records the audio and takes observation notes. At the end of eight minutes, the facilitator starts a conversation with the participants, hands over the PlaTUI Tool to fill up and asks simple questions about the test. Throughout this whole process, precautions are taken to ensure that the children are 1.5 meters apart. The cycle is repeated for stimuli B in the same manner.

test tasks

Stimuli A
Reconfigure the 9 rigid blocks into something that doesn't fall apart.

Stimuli B
Reconfigure the 9 soft blocks into a unified block and inflate/deflate the unified block together

measures

Comparison of observation sheets, PlaTUI tool and the post test interview are all used to analyse in a qualitative sense.

Considering the explorative nature of this research, no statistical analysis was performed. The observation notes are carried out in an unstructured manner with the goal being to observe closely how their attention shifts towards the toy, towards the stimuli and how much the interaction plays a role in these behaviours.

Post task interview with facilitator (guiding questions) (Donker and Markopoulos (2002))
These are the questions which the facilitator poses the children at the end of each activity.
How do you describe the touch of the product?
Did you enjoy what you were doing?
Was it difficult to complete the task?

The PLATui tool is also given for filling up the questionnaire and to take notes in parallel while they are describing.

research findings

As the study was conducted with three participants, it was difficult to arrive at a qualitative conclusion based on the size of the user group. However, it was possible to get recommendations for the working prototype through the observation studies and the PLATui tool.

Name (Participant 1)
Age 8
Sex Male
Would you like to play again?

	No	Maybe	Yes
			Yes

Name (Participant 1)
Age 7
Sex Female
Would you like to play again?

	No	Maybe	Yes
		Maybe	

Name (Participant 1)
Age 6
Sex Male
Would you like to play again?

	No	Maybe	Yes
			Yes

conclusions

It is difficult for a single person to inflate the block all by themselves, as it was observed that they required external help in most of the cases. To overcome this, a more compact and easy to use inflation system was designed (Appendix D.3)

There was an additional difficulty in connecting the vinyl tubing systems to the modular soft inflatable blocks. This was overcome using a very specific interconnector which was easy to push, easy to pull and retained air while pumping. (Appendix D.4)

As observed, the soft squishy nature of the blocks were friendly and accessible, providing a very inviting experience for both boys and girls. However, it was difficult to determine the exact influences owing to the limitations in terms of the number of participants this hypothesis was tested with.

A.2 design test 2

goal

To determine if kids could grasp and interpret closed air systems and if they could intuitively make connections for the same.

Introduction to Research

method

In total four participants participated in this study. All the four were members of the De Bouw Bonteplaats, a LEGO Playspace and are chosen in consultation with the educator. The signed consent forms can be found in the Appendix
Inclusion criteria
Children of age 4 to 7
Informed consent from parents
Member of De Bonte Bouwplaats

Exclusion criteria
Bedridden/ not participating in any activities

Materials required for the test
Pen, Paper for the PLATUI sheet
Observation guide sheets
Guiding questions for the facilitator (post test interview)
Stopclock

Object and Stimuli

The squishy blocks along with the connector pieces, syringe and the port system together comprises of the test stimuli.

Instructions given to the facilitator
Stack the rigid blocks into one combined structure
Inflate the combination of soft blocks together

Environment and Test Setup
The participants are seated across the table with the stimuli objects placed in front of them (A and B). Two roles are assigned amongst

the researchers. One moderator, and one observer. A professional facilitator is present during the test.

The test takes place in the activity area of De Bonte Bouwplaats. The observer takes an unobtrusive position in the room, as much away from the children and the setup as possible, also maintaining a proper distance. The environment is set up for one participant at a time. 10 minutes of time is given for the completion of each task.

test protocol

To minimise the disturbance, the observer takes a place in the room first. After a few minutes, when the participant has no attention for the observer anymore, the moderator places the object in front of the table, without giving any explanation.

When the test starts, the first stimuli A is given and a design challenge is given to them. While this is carried out, the observer records the audio and takes observation notes. After the end of eight minutes, the facilitator starts a conversation with the participants, hands over the PlaTUI Tool to fill up and asks simple questions about the test. Throughout this whole process, precautions are taken to ensure that the children are 1.5 meters apart.

Test Tasks
For the participant, the task given is to use all the 6 squishy blocks together and make a closed air system which can be inflated together by means of a syringe. The participant is given an explanation of the different types of connectors — The stoppers, the interconnectors, etc in advance to show how the prototype could be used to achieve various stacking arrangements.

measures

Comparison of observation sheets, PlaTUI tool and the post test interview are all used to analyse in a qualitative sense.

Considering the explorative nature of this research, no statistical analysis was performed.
The observation notes are carried out in an unstructured manner with two major goals - To observe how they are able to grasp and interpret the stimuli and to understand their ability to interpret different closed air systems.

Post task interview with facilitator (guiding questions) (Donker and Markopoulos (2002))

These are the questions which the facilitator poses the children at the end of each activity.

How did you like playing with this and how was it compared to the previous time?
Did you enjoy what you were doing?
Was it difficult to complete the task?

The PLATui tool is also given for filling up the questionnaire.

results

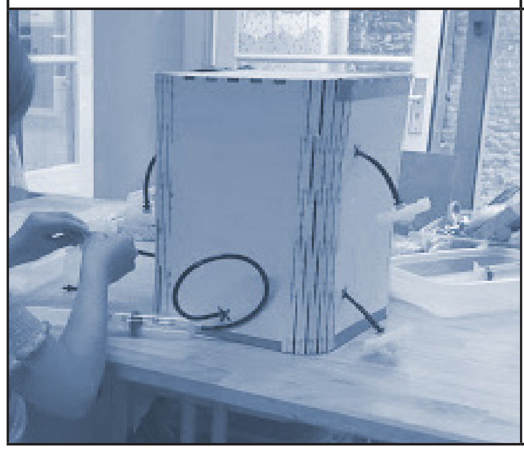
Participant 1 (8 year old male) was interested in connecting the limbs together and building on top of what was already given.
Demonstration of final output with inflation

This was slightly more advanced as compared to the way the other participants constructed the inflatable set.

Participant 2

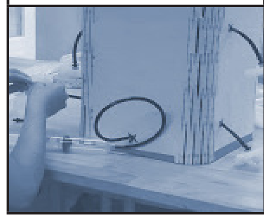
Name (Participant 1)
Age 8
Sex Male
Would you like to play again?

	No	Maybe	Yes
			Yes

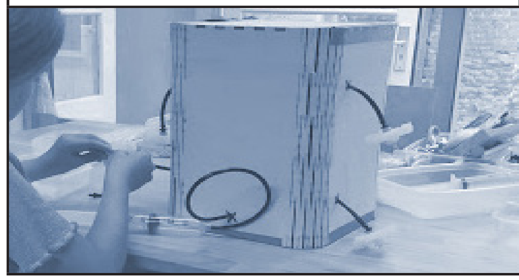
	More such blocks to play and tinker with End connectors should be made easy to fit onto the inflatibits Finding it difficult to squeeze the connectors into the squishies Extending the connectors to help in free-range motion and also flexibility of the limbs

To make this game more fun, what would you add?

Participant 2
Age 6
Sex Female
Would you like to play again?

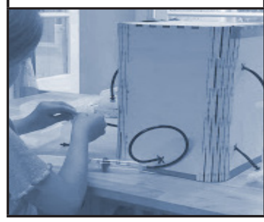
	No	Maybe	Yes
		Maybe	

To make this game more fun, what would you add?

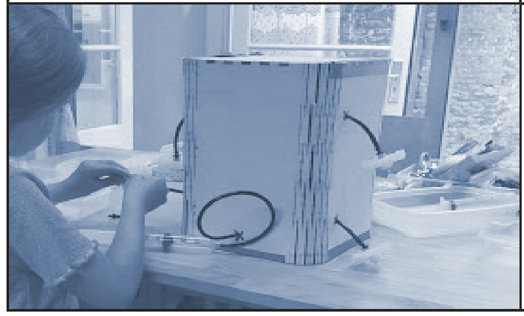
	Difficulty in connecting the caps Can add stars and flowers (wants more designs and different creations and not just limbs)

Participant 3
Age 8
Sex Female

Would you like to play again?

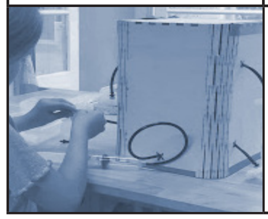
	No	Maybe	Yes
			Yes

To make this game more fun, what would you add?

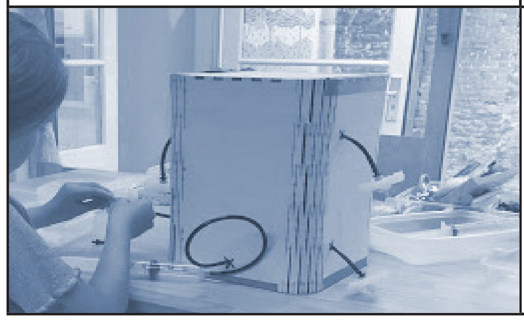
	Connectors were confusing. so it should be made less confusing. Should be more versatile in terms of ways in which it could be fitted

Participant 4
Age 5
Sex Male

Would you like to play again?

	No	Maybe	Yes
			Yes

To make it more fun, what would you like to add?

	Should be able to connect the syringe to various ends and not just one place Enjoyed the action of inflation, but still found it difficult to connect the blocks

conclusions

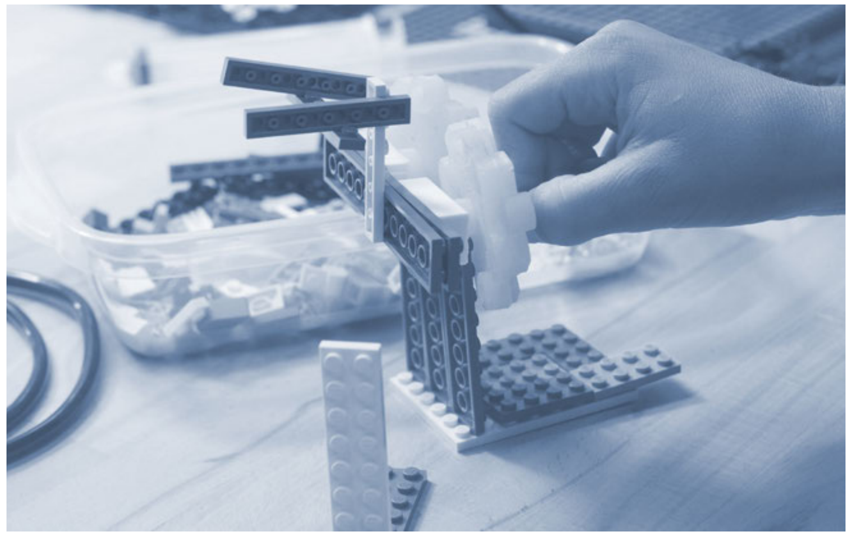
Make the design normally closed air system instead of normally open by default.
Modify the end connectors of the inflatable modular blocks so that they are easier to connect with each other. (Appendix D.4)
Magnetic connectors should be tested with children.
It should be possible to combine different limbs together, and by imagining air systems like a circuit to create different kinds of body movements.
It should be possible to extend the connectors in such a way that free range motion is made possible by providing more flexibility to the limbs.
Children understood closed air systems quite intuitively, provided that they were given instructions or some basic inspiration as to how the system behaved. This helped them to create their own systems using the wide variety of modular blocks which could be stacked in various ways. This helped in providing more open ended play.

A.3 design test 3

Goal
To determine if kids could interconnect the inflatable blocks easily and are able to make their own LEGO designs including the soft blocks

Introduction to Research
Method
In total three participants participated in this study. All the four were members of the De Bouw Bonteplaats, a LEGO Playspace and are chosen in consultation with the educator. The signed consent forms can be found in the Appendix
Inclusion criteria
Children of age 5 to 8
Informed consent from parents
Member of De Bonte Bouwplaats

Exclusion criteria
Bedridden/ not participating in any activities
Materials required for the test
Pen, Paper for the PLATUI sheet
Observation guide sheets
Guiding questions for the facilitator (post test interview)
Stopclock
Object and Stimuli



Test Protocol
To minimise the disturbance, the observer takes place in the room first. After a few minutes, when the participant has no attention for the observer anymore, the moderator places the object in front of the table, without giving any explanation.

When the test starts, the LEGO Blocks along with the soft modular blocks and the interconnectors are given and they are given as a task to use the LEGO pieces and the inflatable blocks together.

While this is carried out, the observer records the audio and takes observation notes. After the end of eight minutes, the facilitator starts a conversation with the participants, hands over the PlaTUI Tool to fill up and asks simple questions about the test. Throughout this whole process, precautions are taken to ensure that the children are 1.5 meters apart.

Measures
Comparison of observation sheets, PlaTUI tool and the post test interview are all used to analyse in a qualitative sense.

Considering the explorative nature of this research, no statistical analysis was performed.
The observation notes are carried out in an unstructured manner with the goal being to observe how they are able to grasp and interpret the stimuli and their ability to develop different closed air systems.

PlaTUI Tool

Participant 1
Age 4
Sex Female

Would you like to play again?

	No	Maybe	Yes
			Yes

To make this game more fun, what would you add?

	Interconnectors are still a bit frustrating, and not sure how the soft blocks are to be squeezed to make sure that it fits to the hard blocks of LEGO

Participant 2
Age 6
Sex Female

Would you like to play again?

	No	Maybe	Yes
			Yes

To make this game more fun, what would you add?

	Not able to think of other possibilities of side by side arrangements with LEGO. All I can think of is vertical stacking

Participant 3
Age 6
Sex Male

Would you like to play again?

	No	Maybe	Yes
			Yes

To make this game more fun, what would you add?

	Sometimes the vinyl tubing comes of, which means it should be airtight and also quite tight

Participant 3
Age 6
Sex Male

Would you like to play again?

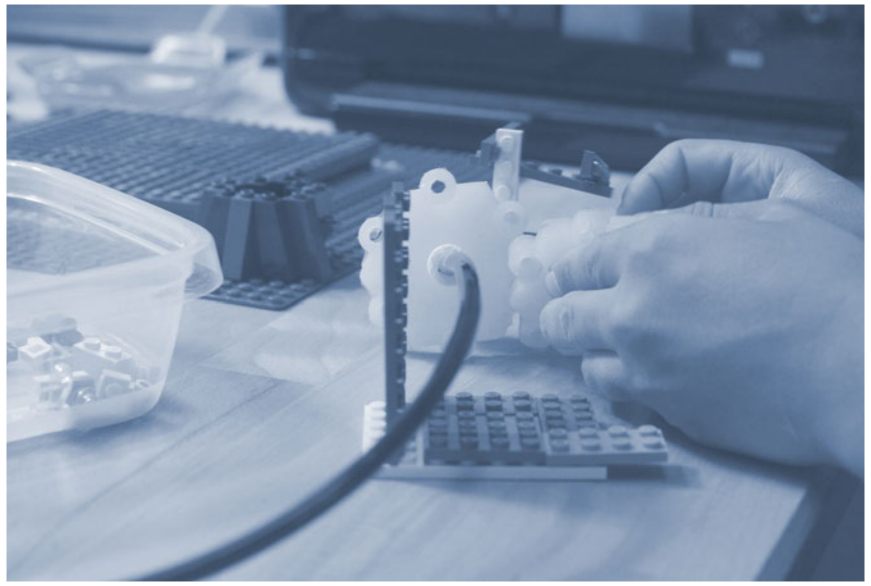
	No	Maybe	Yes
			Yes

To make this game more fun, what would you add?

	Not able to think of animals which can walk by means of this using LEGO

Conclusions and Recommendations

It was easier to interconnect the soft modular blocks because of the tapered ends.



Although LEGO blocks were handed over for the children to combine and make new models, it needed a prior set of instructions for them to understnad how well the inflatable blocks could combine with LEGO.

The children needed prior training in understanding how to connect the modular blocks using the interconnectors as this was pretty new for them to engage with. As a recommendation, an interactive instruction manual that could go hand in hand with the modular blocks is recommended, illustrating how they could combine and interact with.

As the focus of this test was primarily on the adaptibility of the existing set of modular blocks with the LEGO ecosystem, the syringe inflation action was not given much focus. It is recommended by the conclusions on this test that the syringe action could be tested

All the four participants wanted to continue playing with the soft actuators based on the PLATUI Tool indicating that there is less reduced frustration for connecting the blocks together.

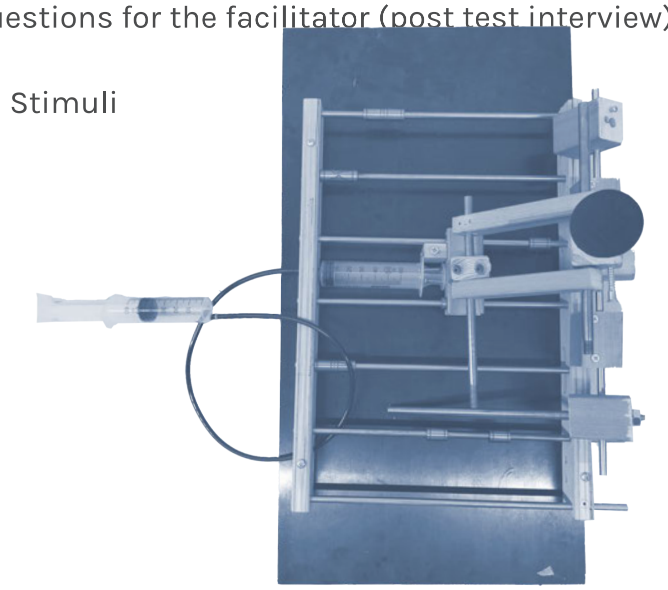
A.4 design test 4

Goal
To determine the pain points in the overall inflation experience

Introduction to Research
Method
In total two participants participated in this study. All the four were members of the De Bouw Bonteplaats, a LEGO Playspace and are chosen in consultation with the educator. The signed consent forms can be found in the Appendix

Inclusion criteria
Children of age 4 to 7
Informed consent from parents
Member of De Bonte Bouwplaats

Exclusion criteria
Bedridden/ not participating in any activities
Materials required for the test
Pen, Paper for the PLATUI sheet
Observation guide sheets
Guiding questions for the facilitator (post test interview)
Stopclock
Object and Stimuli



Test Protocol
To minimise the disturbance, the observer takes place in the room first. After a few minutes, when the participant has no attention for the observer anymore, the moderator places the object in front of the table, without giving any explanation.

When the test starts, the LEGO Blocks along with the soft modular blocks and the interconnectors are given and they are given as a task to use the

While this is carried out, the observer records the audio and takes observation notes. After the end of eight minutes, the facilitator starts a conversation with the participants, hands over the PlaTUI Tool to fill up and asks simple questions about the test. Throughout this whole process, precautions are taken to ensure that the children are 1.5 meters apart.

Measures

Comparison of observation sheets, PlaTUI tool and the post test interview are all used to analyse in a qualitative sense.

Considering the explorative nature of this research, no statistical analysis was performed.
The observation notes are carried out in an unstructured manner with the goal being to observe how they are able to grasp and interpret the stimuli and their ability to develop different closed air systems.

PlaTUI Tool

Participant 1
Age 4
Sex Male

Would you like to play again?

	No	Maybe	Yes
			Yes

To make this game more fun, what would you add?

	Not able to think of how to add to LEGO, some instructions on how that could help might be useful

Participant 2
Age 6
Sex Male

Would you like to play again?

	No	Maybe	Yes
			Yes

To make this game more fun, what would you add?

	Needs more variety of motions, and multiple ways to make it move, not just leg movement.

conclusions

The tapered connector (Appendix D.4) still showed a sense of frustration for children to connect the blocks with each other.

To accomodate this, a better version (Fig. D.4 a) was developed to reduce the overall frustration experience for children

The bending actions were not specifically controlled by means of the bending restrictors which were provided. To accomodate that, an accompanying guidebook is suggested as a recommendation to make sure that they are able to creatively use all the components.

The syringe inflation system as shown in (Fig D.3 b) was quite heavy and was difficult to lift and fix to the table. For the next iteration, the inflation system could be made more smaller with individual modular units that could be attached to each other.

A.5 conversational interviews

Name	Date	Minutes of the Meeting
Stefan van de Geer	April 17, 2020	How should the test be designed. Arrange all the design tests with children. Get the ethical permissions for conducting the tests. Make a list of assumptions before entering into the prototype with which you could test the assumptions.
Alice Busso	May 25, 2020	Design custom molds for the sensors, make an inlet and outlet valve so that there are not so much air bubbles which are formed.
Rob Scharff	May 29, 2020	Discussing the key embodiment challenges Identifying different types of drip irrigation valves which could be used for the project Resistive sensing of silicone is possible if there is any requirement to make silicone based sensors. TUBALL is a good option for the same.
Tessa Essers	May 28, 2020	Discussing potentialities on how flexible filaments could be used. TPU Shore 95 is a good option for my purpose. Polyjet printer could be used for the application, but it should ensure that they required stl file is possible to print.

Name	Date	Minutes of the Meeting
Adrie Kooijman	June 15, 2020	How to use supermagnets in my current application? NdFeB magnets could be used for this application. As they are ring magnets, they could not prevent any discontinuity in the air flow.
Martin Verwaal	June 17, 2020	Meeting to discuss how sensors could be integrated into the body of the silicone. In order to estimate the pressure range of the sensors, a pressure sensor could first detect the range of the device and then find an appropriate sensor.
Wiebe, PMB Lab	June 17, 2020	Discussed how the pressure sensors for touch, squeeze and twist could be interfaced with the body of the squishy toy.
Stefan van de Geer	June 29, 2020	It is important to have rounded corners for the product as it is mainly used by children. Sam de Visser's six rules of aesthetics might be helpful for character design. - For the animal character animation: Facial expressions are important. So study various facial animations and see which portray disgust or surprise, or chubby or cute and then use those potentially in the character animation and storytelling. - There are various axes for thinking such as axial, linear, radial and circular to understand the emotions - Desmond Morris - Posture of Apes is an important book to study the body language of humans through apes. - Semantics becomes important, the hidden meaning behind things and language. - For hydraulics, there could be a sterling engine mechanism, available on thingiverse, and the guy makes special brackets for the same.
Stefan van de Geer	June 6, 2020	Cross verify the pot magnets from the website and check how well it could be used for the application. Magnets could also be dangerous for children as it could lead to potential hazards while swallowing.

appendix B

design methods

B.1

product experience

B.2
9 MoPE

The Nine Moments of Product Experience was helpful in charting out micro, macro and meta qualities in relation to aesthetics, meaning and emotion.

The key takeaway from this analysis was that adding eyes, immediately adds more emotion to the character and several iterations of the right eye size, dimension to provoke the required emotion of 'cuteness' was crafted. Texture also played a major role, and the sense of the product being squishy made it more playable and inviting for children to interact with it.

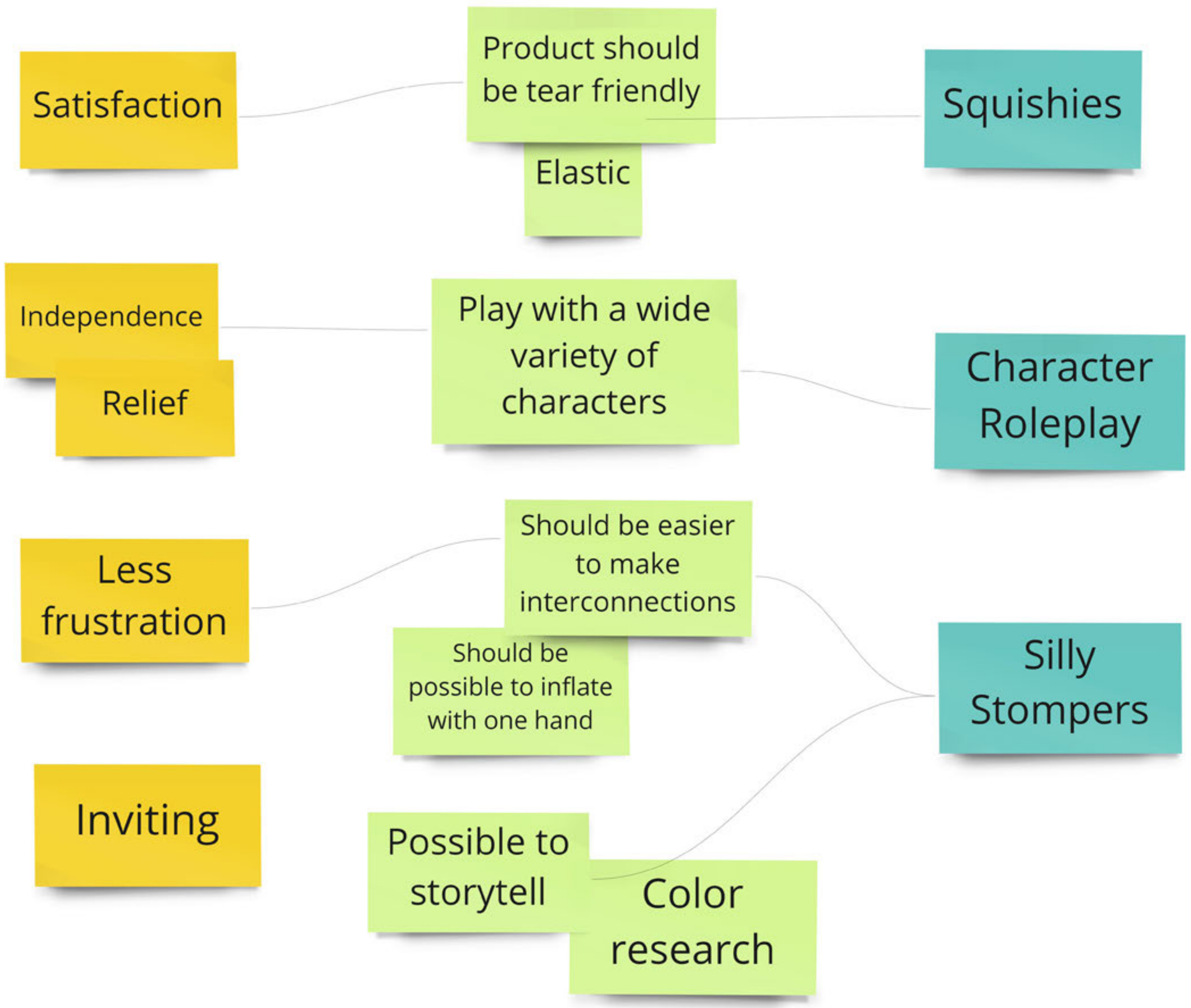


Fig. (B.2) Connecting emotional properties to product properties

moodboard

B.3
morphological chart for gestures

Using the technicalities and potentialities workflow (Poelman, 2005) the concept of Silly Stompers emerged by taking the morphological chart for gestures into account. For the character design, the required gesture through hand and body movement which is still possible via soft actuator inflation was brainstormed and charted out. Out of this, 'stomping' emerged as the right gesture which could both be technically feasible, and also invoked the emotion of cuteness making it interesting for younger children.

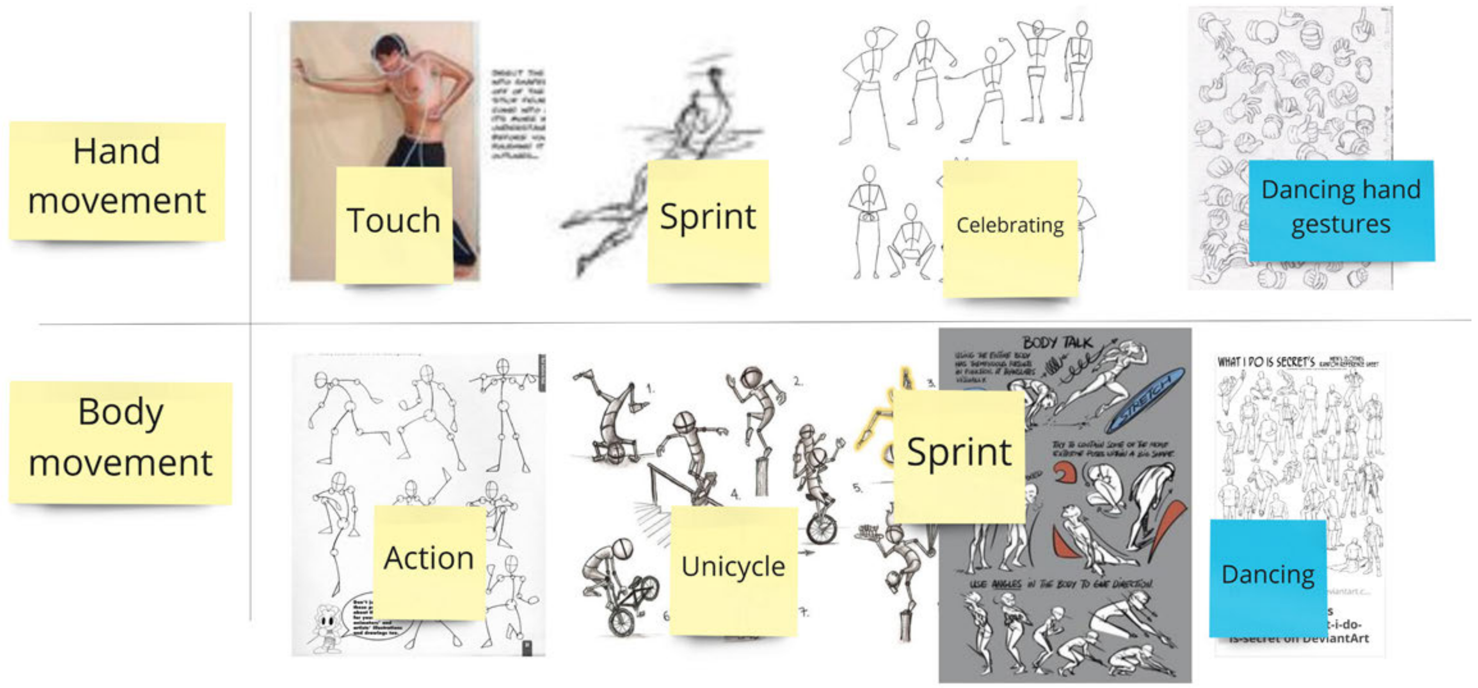
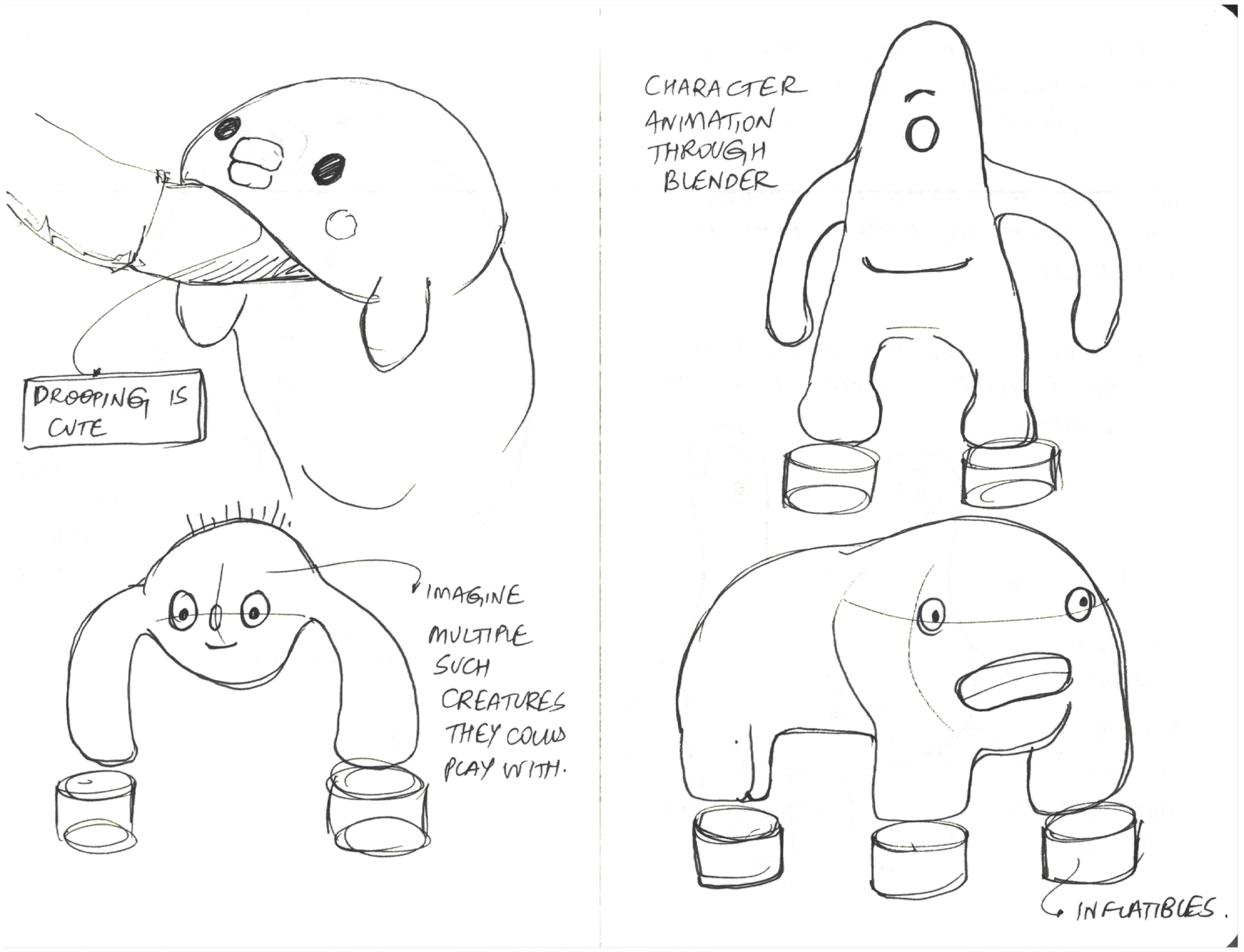


Fig. (B.3) Weighted criteria method for evaluating and selecting the concept for the next stage



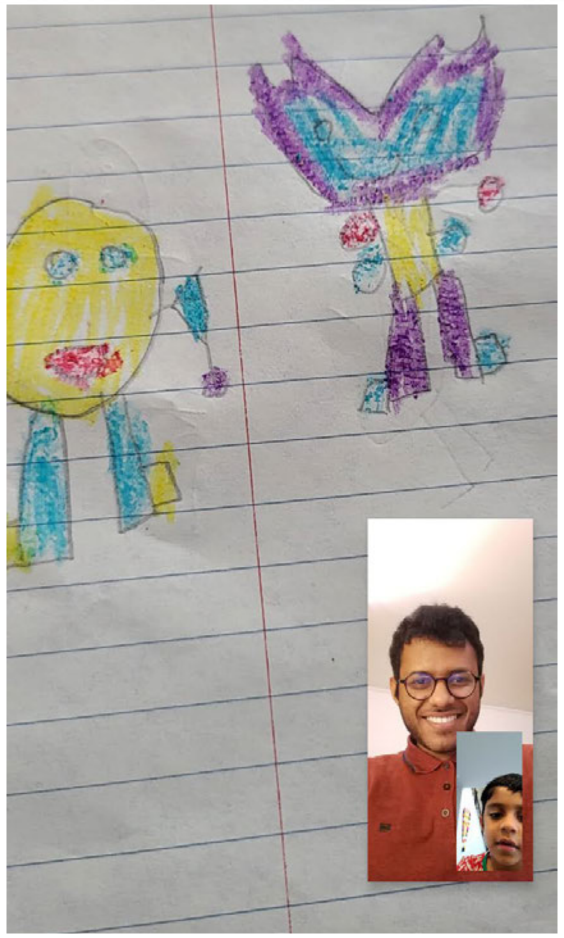


Fig. (B.3 a) Co-creation with a 5 year old on possible ways to 'stomp' through various characters.

character moodboard

Based on sampling, and sensory analysis ans shown in the 9 MoPE, and involving in co-creation with a 5 year old wherein the sketches for alien creatures and custom creations were explored. From all these inspirations and sketches, the final form of the silly stompers were refined.

B.4
overall assembly

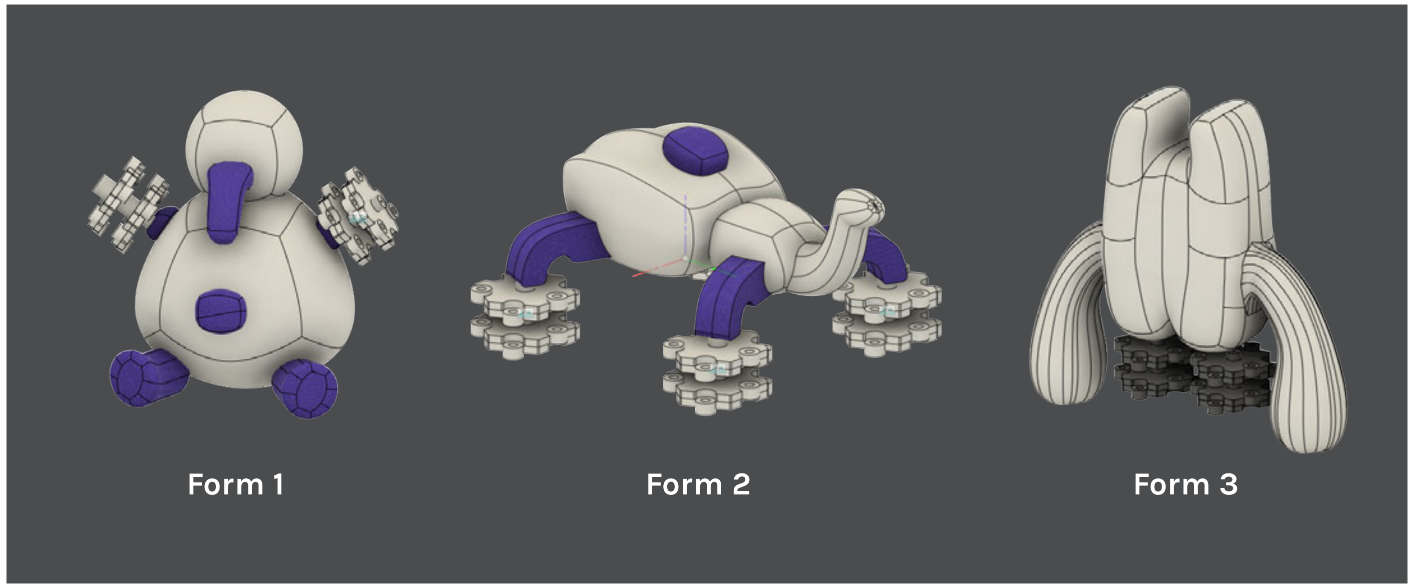


Fig. (B.4 a) Three various forms were iterated upon based on the overall idea of invoking 'Silly Stompers'.

For the final form of the creature, three various types were choosen. These were considered based on how the modular blocks could be used to lift and move the creatures accordingly.

Form 3 was choosen over the other forms owing to the ease with which the inflatable blocks could be used to move the creature whereas Form 2 made it more complicated for children to create basic movements as it required four limbs.

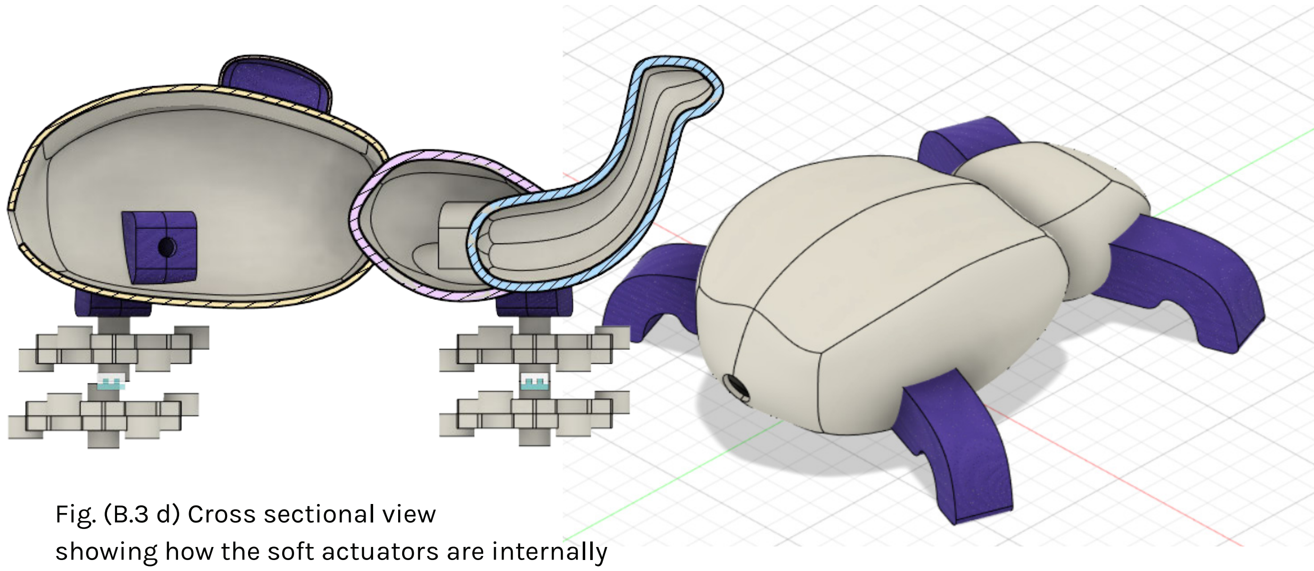


Fig. (B.3 d) Cross sectional view showing how the soft actuators are internally connected to the

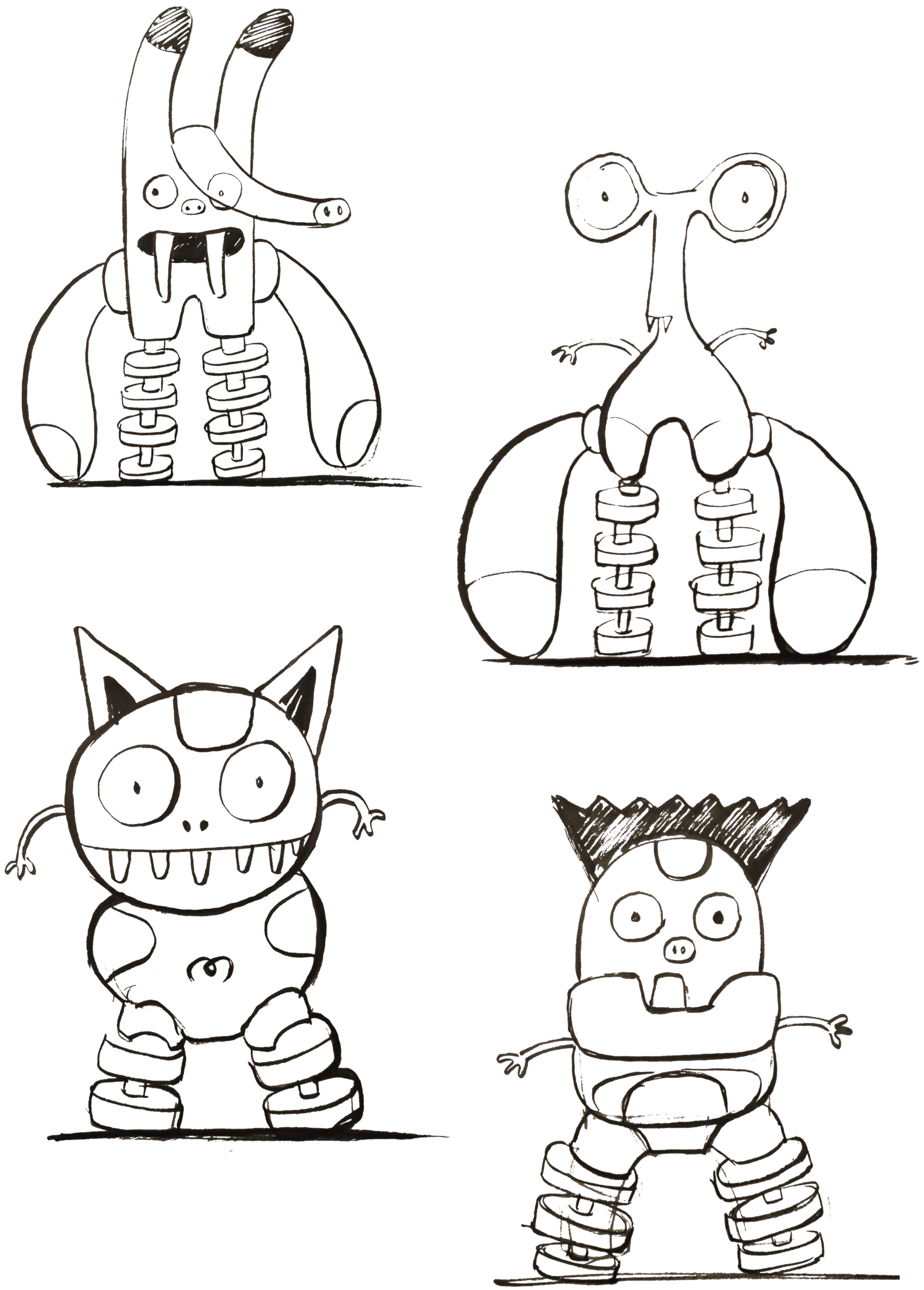


Fig. (B.4 c) Sketches as a part of the brainstorming in arriving at the desired characters of Silly Stompers

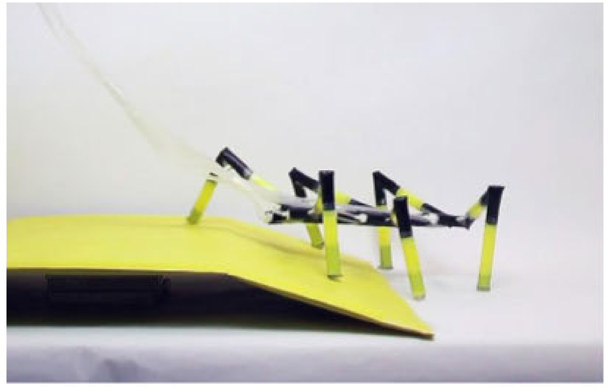
B.5

benchmarking

Benchmarking is done on a very exhaustive way for most of the STEM toys in the market, partly to understand the potential gaps, and partly for more idea generation through synectics (Chapter 2.4)

benchmark analysis

Arthrobots



Type	Inflatible robots
Working Principle	Inflating balloons with straws to make creatures move in interesting ways
Price	Research project (low cost)
Brand	Harvard
Description and Specifications	Used to conduct soft robotic workshops for younger children Helps children understand concepts of locomotion
Target Group	Children aged 4-7

Woobo

Type	Smart companion for younger kids
Working Principle	Tactile sensory toy
Price	250 euros
Brand	Woobo
Description and Specifications	Plays games and teaches concepts Inspired to learn with Woobo Has voicemails, audio narration
Target Group	4-7 years old

Unruly Splats

Type	Learn coding
Working Principle	Learn coding through dance, tap sensor activates
Price	130 euros
Brand	Unruly Splats
Description and Specifications	Combining coding through physical activity into computational thinking Sensors, programmable LEDs, 3AA Batteries
Target Group	6+

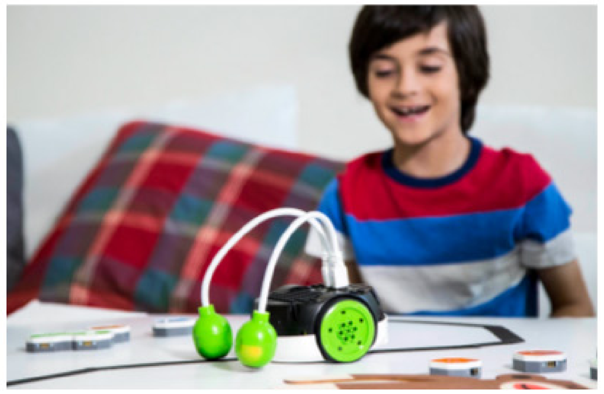
Toyi

Type	Creative toolkit
Working Principle	Set of connectors that can transform everyday objects
Price	25 dollars
Brand	Toyi
Description and Specifications	Creative play kit without instructions that enables children to transform everything around them into unique toys. Flexible connectors - Foot, hand, wheel, eye, joint, stick
Target Group	Children aged 6+

Squishy Circuits

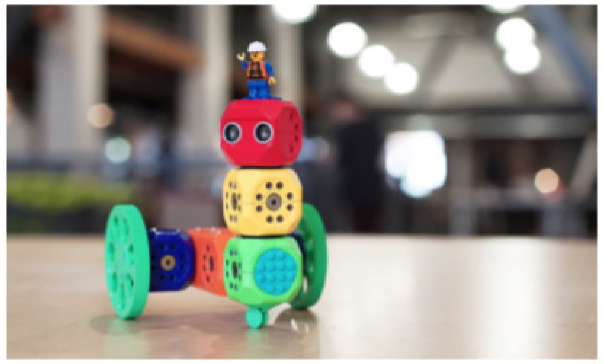
Type	Learning electronics basic
Working Principle	electrodough
Price	25 dollars
Brand	Squishy Circuits
Description and Specifications	1 - Deluxe Battery Holder 1 - Piezoelectric Buzzer 1 - Motor with Fan 1 - Mechanical Buzzer 1 - Switch
Target Group	6+

Robopal



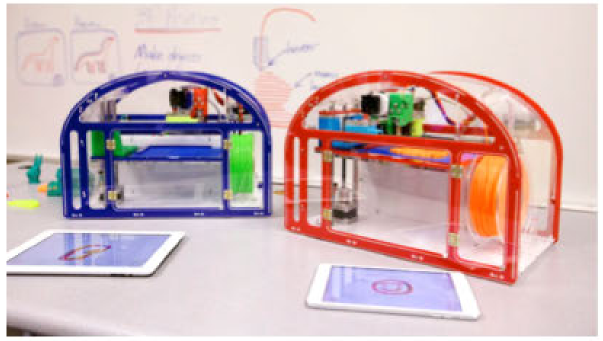
Type	Learning coding
Working Principle	Magnetic coding blocks which controls bot
Price	160 euros
Brand	Robopal
Description and Specifications	• Robot • 9× Coding Blocks • 2× Accessories • 4× Cables • Storybook
Target Group	7+

Robo Wunderkind



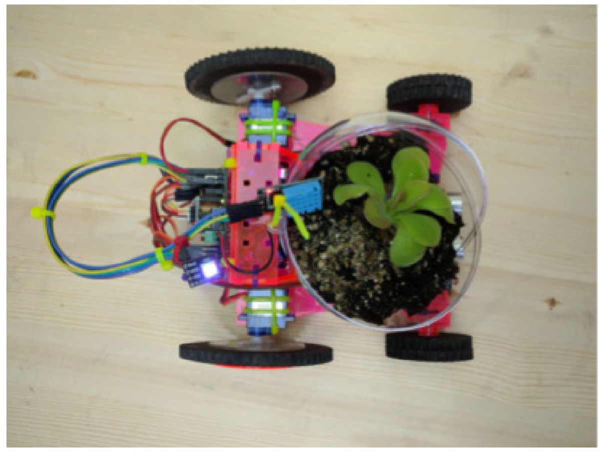
Type	Coding based robot toy
Working Principle	Integration of blocks, apps, community
Price	250 dollars
Brand	Robo Wunderkind
Description and Specifications	12 programmable robo blocks, Robo Universe app, Robo Wunderkind community
Target Group	5-12

Printeer



Type	3D printer for kids
Working Principle	3D Print your own creations using iPad, simple kid-friendly 3D printer
Price	550 euros
Brand	Mission Street Manufacturing
Description and Specifications	16 inch (406 mm) wide x 9 inch (229 mm) deep x 12 inch (305 mm) high Weight: 12 lbs (5.5 kg) Fully enclosed
Target Group	Broad and diverse, kids K-12

Plantoid



Type	Bot based programming
Working Principle	Plants in search of light and water for its own growth
Price	
Brand	
Description and Specifications	Organic plant-robot cyborgs • Soil moisture • Air temperature and humidity • Ambient light • Air quality sensors.
Target Group	7+

Phiro

Type	Smart robot for kids to learn in five different ways
Working Principle	LEGO Compatible programmable robot
Price	80 dollars
Brand	Robotix
Description and Specifications	Coding concepts using free-open source programming Navigate room, connect with LEGO, sing etc
Target Group	5-12

Plobot

Type	Physical coding for ages 4 and up
Working Principle	Programming logic through storytelling instead of screens
Price	120 euros
Brand	Plobot Team
Description and Specifications	Through command cards, base set and a list of functions (color cards, function cards) Size: 15 * 20 * 10 cm
Target Group	4+

Osmo blocks

Type	AR based coding using iPad
Working Principle	Augmented Reality
Price	80 euros
Brand	Osmo
Description and Specifications	Hands on games to engage pre schoolers
Target Group	6-10

Open Toys

Type	Transform fruits and vegatables into playful objects
Working Principle	Creative playkit
Price	20 euros
Brand	Tactile sensory toy
Description and Specifications	3D printed accessories
Target Group	4+

Offbits

Type	Upcycled components - DIY robots
Working Principle	Upcycled assembling components
Price	50 euros
Brand	The offbits
Description and Specifications	• Cable clamp - steel alloy, finished and painted • Nuts - various sizes (mostly M4, M6, M7), steel alloy, paintedalloy
Target Group	

Mutable

Type	Furniture - Multi-activity play table
Working Principle	Interchangeable furniture with connectors
Price	200 euros
Brand	Mukako
Description and Specifications	Adjustable heights 7 activities included
Target Group	4+

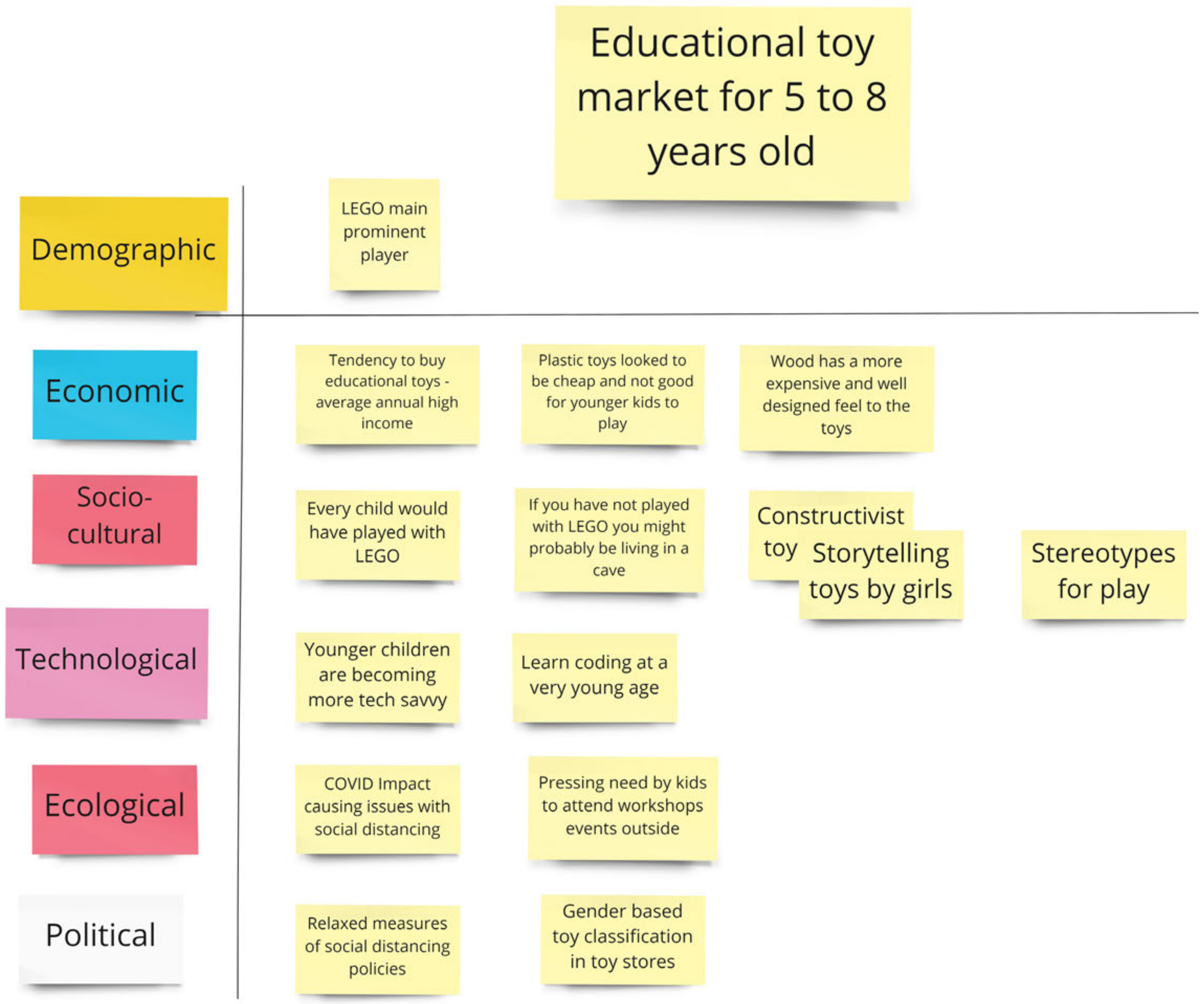
Musicon

Type	Music based coding
Working Principle	Marble based movement easy to code and interface by pressing buttons
Price	2800 euros
Brand	Musicon Club
Description and Specifications	Learning coding and musical composition, analog sound quality with drums, xylophone etc
Target Group	Ages 3+

Makeblock Neuron

Type	Electronic sensor actuation blocks which are plug and play
Working Principle	Digital interface for programming, bluetooth connection
Price	220 euros
Brand	Makeblock
Description and Specifications	It consists of LED panels, motors, LEDs, Actuators etc, Flow based programming language
Target Group	7+

B.6
trend analysis



(Fig. B.6 a) Demographic, Economic, Political, Ecological, Social and Technological trends evaluated

DEPEST analysis was done to accomodate all the major fronts of the landscape such as the political, ecological, social and the technological. It has been increasingly being observed that more younger children are getting into programming. With the advent of LEGO WeDO and NEXT, it has become easier for children to learn programming through easier graphical and tangible interfaces.

As the current trends show the increasing need for matching up to the programming education for younger children, the soft robotic toys which are currently being developed could play a pivotal role. As the product aligns itself towards the front of allowing children to code using air, it becomes more and more adoptable according to the trends shown in the figure.

B.7
color considerations

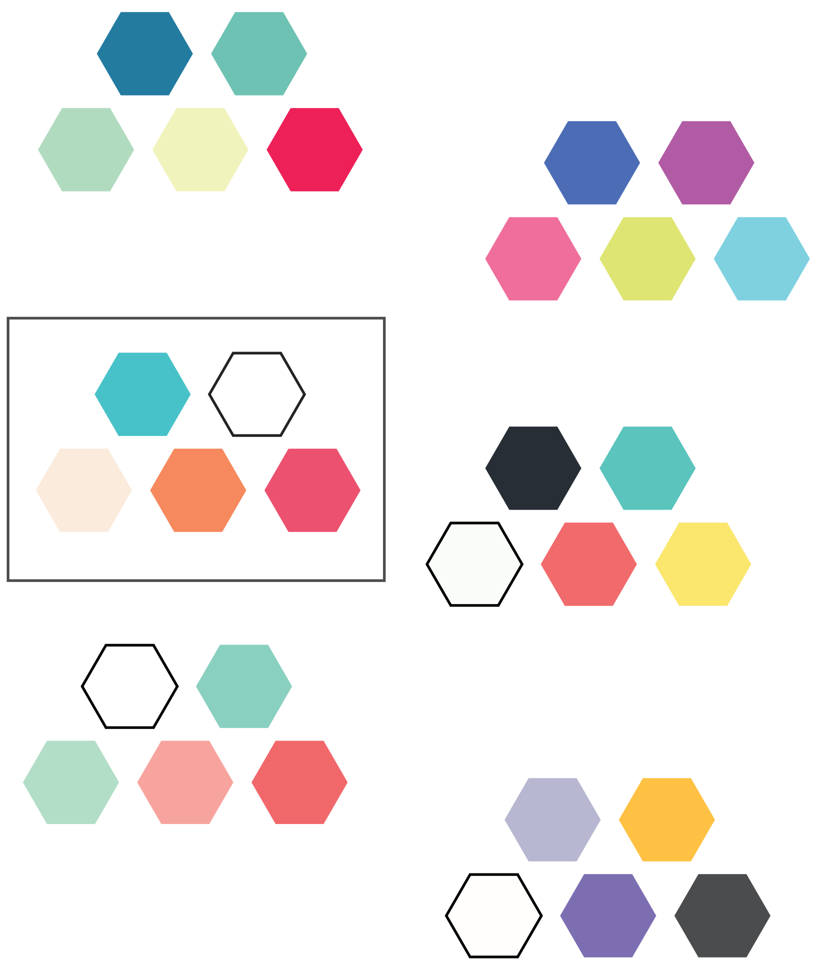


Fig. (B.7 a) Various color palettes explored.

It has been shown that blue is the most popular color scheme for men, whereas brown emerges to be the most unpopular for both men and women.

Taking these as the haves and havenots, further exploration in the color palette was done before arriving at a selection to be used.

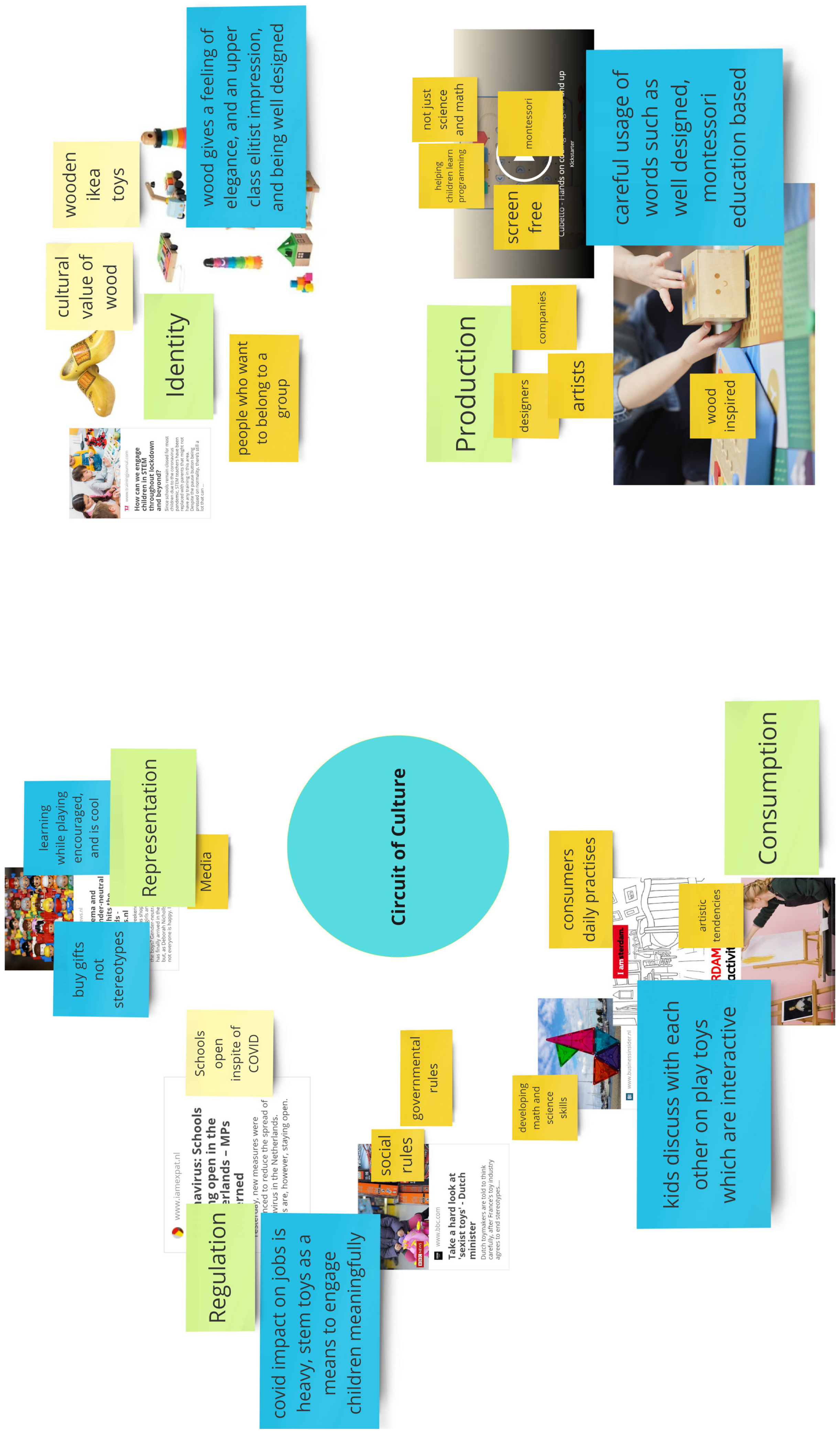


Fig. (B.8) Six aspects of circuit of culture namely representation, regulation, identity, production and consumption based on (Du Gay, 2013)

circuit of culture

B.8

representation

There has been a stronger representation in the media towards moving away from the identity of gender based stereotypes when it comes to toys. Gender neutral toys are increasingly being preferred and are marketed accordingly.

regulation

With the current COVID-19 situation in the Netherlands, there is an increasing focus on adequate social distancing and avoiding group interactions. Although the rules and regulations have relaxed at present because of the drop in the numbers, parents are taking increasing amount of precautions to avoid such group interactions even through toys.

consumption

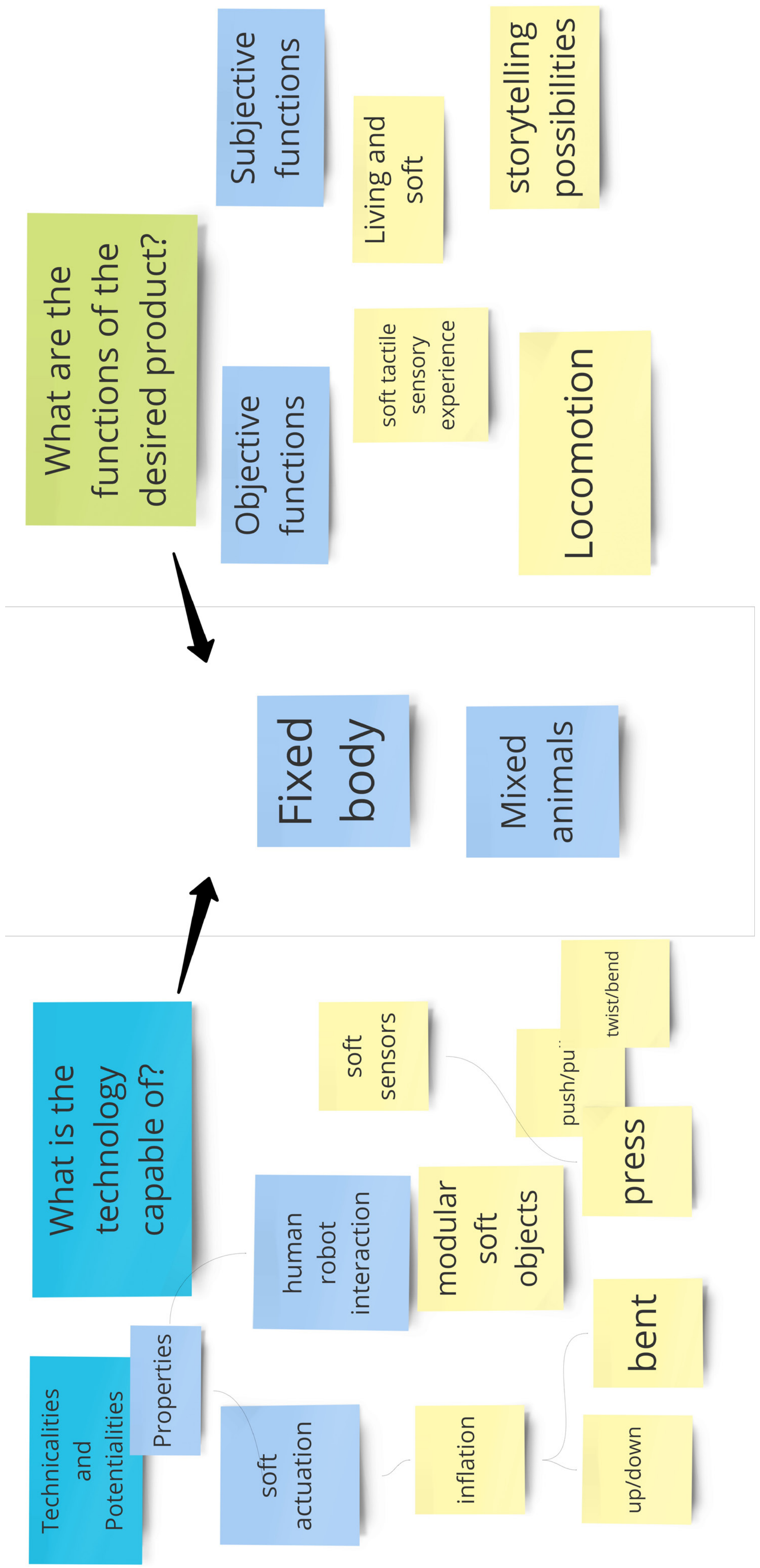
As children are well connected with each other through online platforms, the word of mouth of any such new toy in the market could be increasingly important in this cultural setup.

identity

Wood is very closely associated with the notion that the toys are well designed. Wood is also very closely aligned with the sense that they are quite child friendly. In addition to this, the Netherlands has stronger cultural roots to well designed wooden products such as the Dutch wooden shoe for example.

production

Most of the products already available in the market, which are in the educational toy segment focus on communicating the educational philosophy which the product is deeply rooted in. For instance, most of the screen free toys available for younger kids are portrayed to be of the Montessori/Waldorf school of thought.



B.9

technicalities and potentialities

At the mid-term phase of the project, after arriving at the storyboard for interaction (Chapter 3.2.1) this method was used to understand what could be the desired expression, and story behind the characters that ought to be designed. This method helped in arriving at the desired functions of the product, also ensuring that soft robotics actuation as a technology was used. (Poelman, 2005)

appendix C

planning

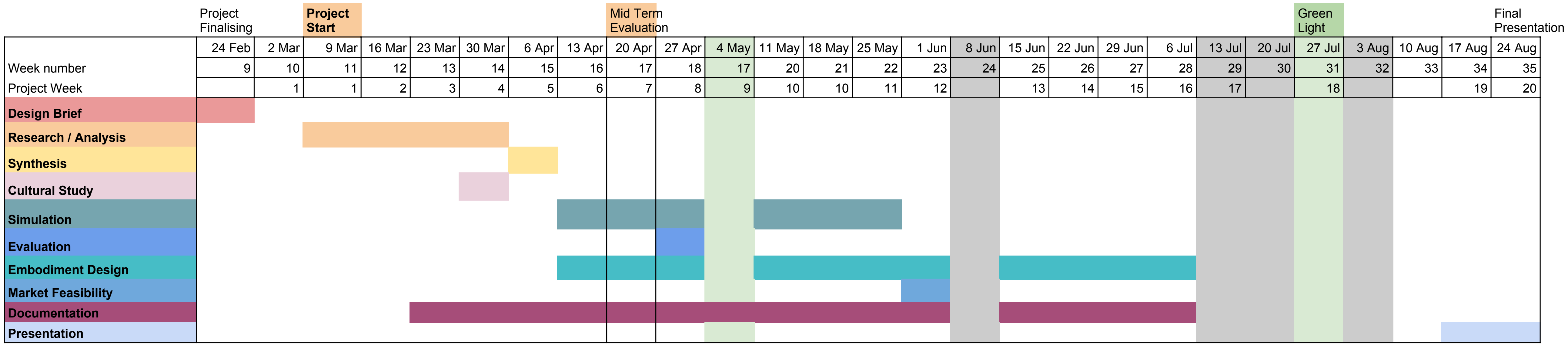


Fig. C Global gantt chart for the graduation thesis

appendix D

embodiment challenges

Fig. (D.1 a) Structural arrangements indicating top-down, lateral ways of connecting these blocks

D.1

leveraging open ended play through various configurations

One of the key challenges which were tackled was to determine how to promote open ended, versatile play using LEGO. For this usage, the hexagonal block shapes of the InflatiBits were used as an inspiration.

The hexagonal blocks are tested for their right dimensions. To see how well children of this age group can involve in lateral, top-down and side by side stacking of these hexagonal blocks, a design test (Appendix A.1) was conducted to determine how well children could use them to adapt and combine in making new structural arrangements.

D.2

air bubble formation in the silicon molds

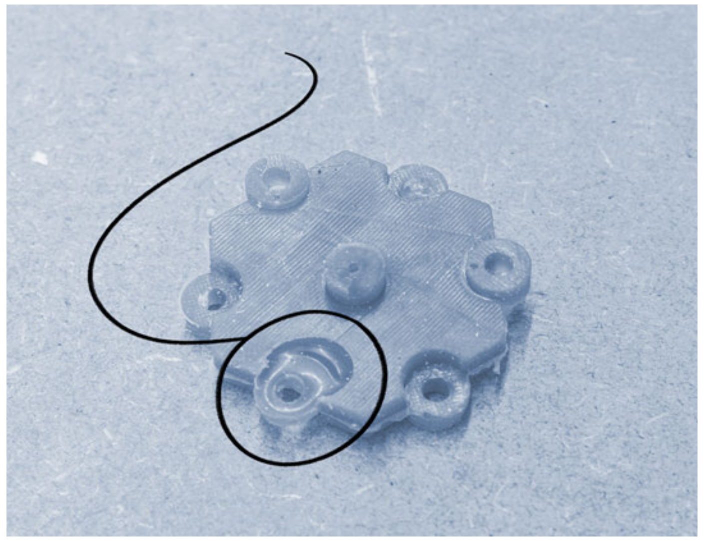
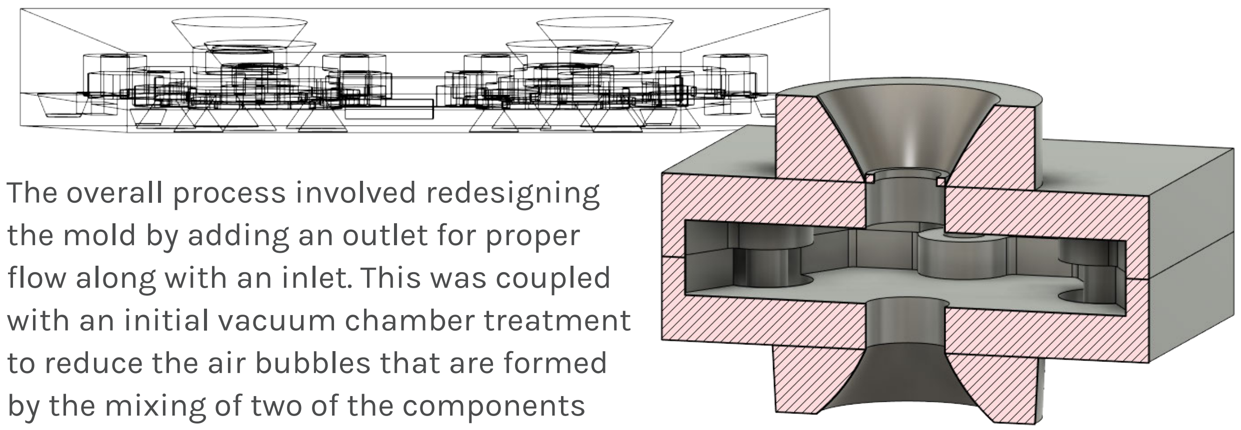


Fig. (D.2 a) Air bubble formation in the initial molds

For the initial set of trials in which the modular blocks were created by designing the molds in which the silicon component mixture was poured and dried until it achieves the desirable shape.

In the initial trials, the air bubble formation persisted inspite of treatment from the air chamber. For the subsequent iterations, the process was changed by redesigning the mold in which the silicone was cast.



The overall process involved redesigning the mold by adding an outlet for proper flow along with an inlet. This was coupled with an initial vacuum chamber treatment to reduce the air bubbles that are formed by the mixing of two of the components (Component A and Component B) in a 1:1 ratio

Fig. (D.2 b) Inlet and outlets provided for better air circulation to prevent any formation of air bubbles

Slow curing, shrink free, soft silicone was used for the material. Using this 1:1 mixture, the adequate amount was measured in a weighing scale and stirred until the mixture becomes even.

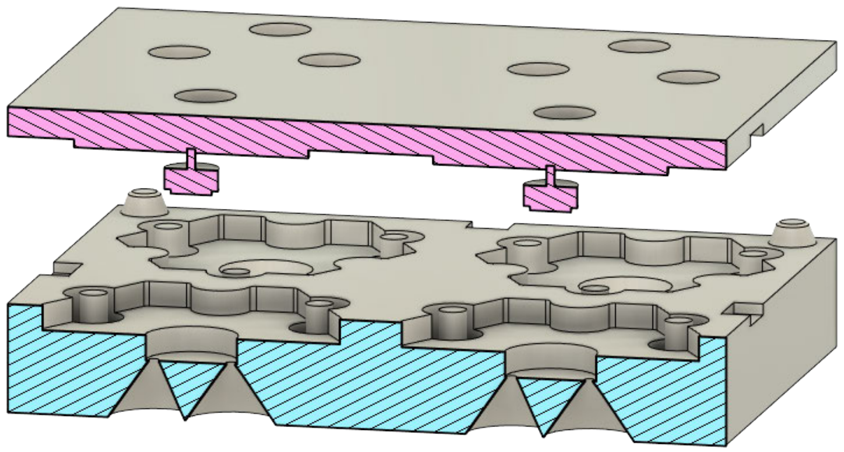


Fig. (D.2 c) Mold design of magnetic soft actuator blocks along with inlet and outlet. (Appendix D.4)

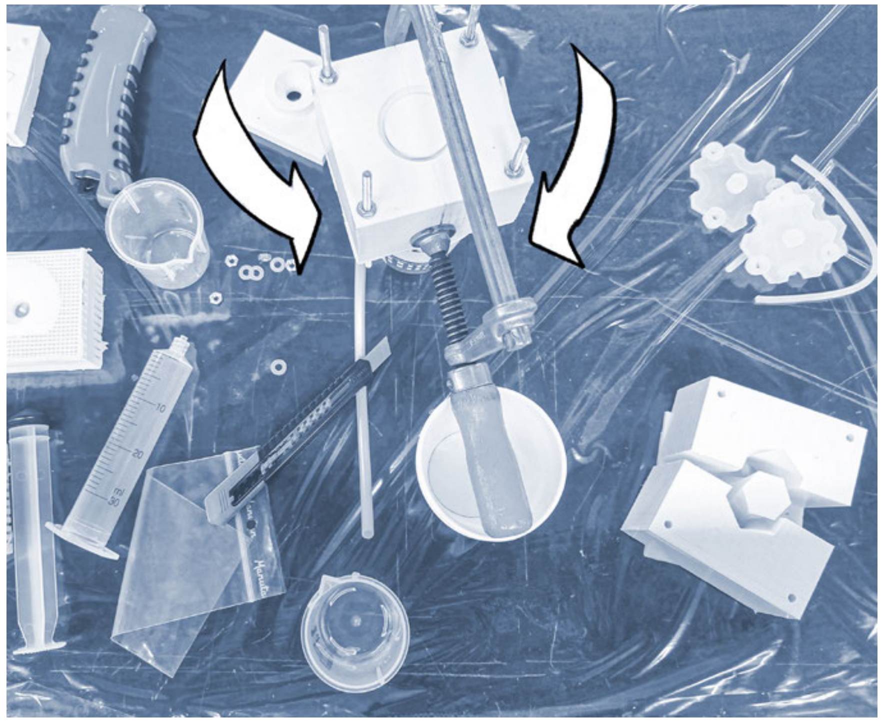
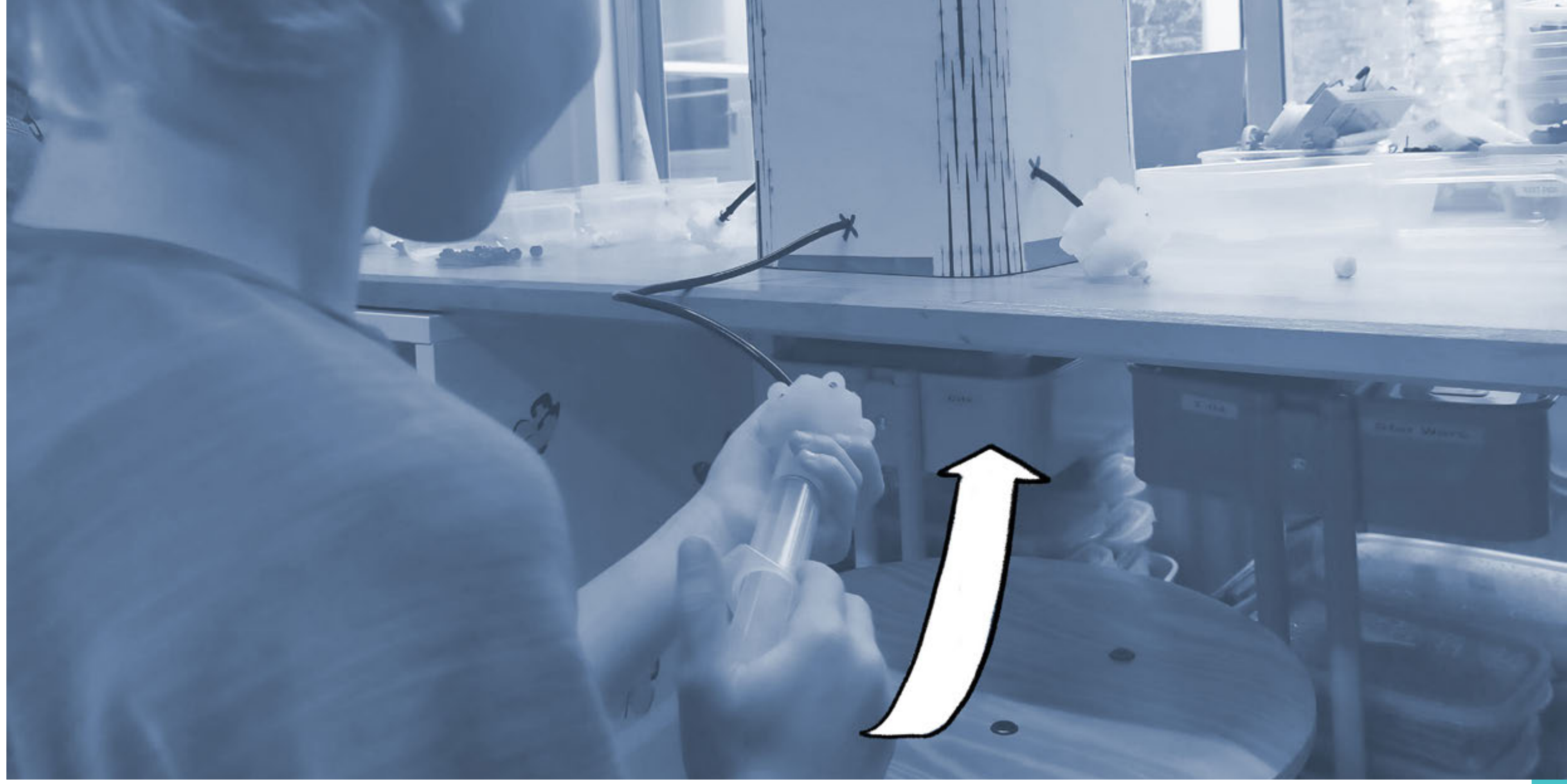


Fig. (D.2 d) Casting process for each mold taking on average 3 hours for Shore 30 hardness silicone material

A two part mold was used to create these modular blocks. During the procress of curing, clamp and screw arrangement is utilised for combining the two silicone components by fixing firmly with each other.

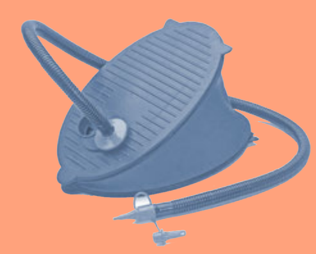


D.3 ease of inflation and deflation with respect to the modular blocks

From what was observed in the design test 2 (Appendix A.2), pumping the actuator blocks was especially difficult owing to holding it with both the hands and having to inflate it. It was necessary for this process to happen just by means of one hand so that it the child focusses less on inflating them, rather than the process of enjoying the movement of Silly Stompers. Reflecting on the conclusions of this test, a benchmark analysis was done to observe and analyse the types of systems already available which can help in easier inflation as follows.

LEGO Pneumatic cylinders

Three port distribution block with valve ports



Foot based pumping

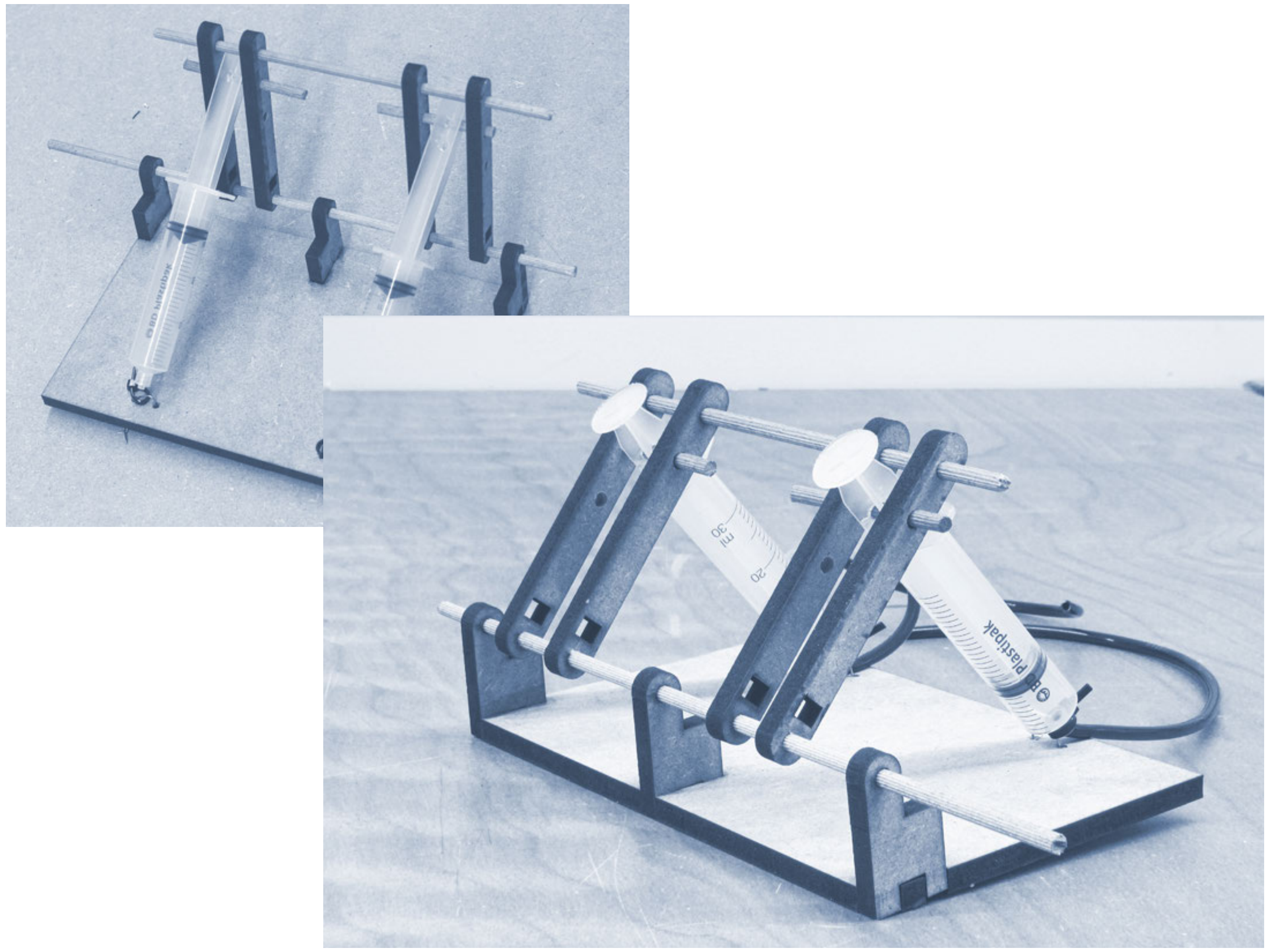
Would be difficult to control multiple blocks by foot

Bellow based hand pumping

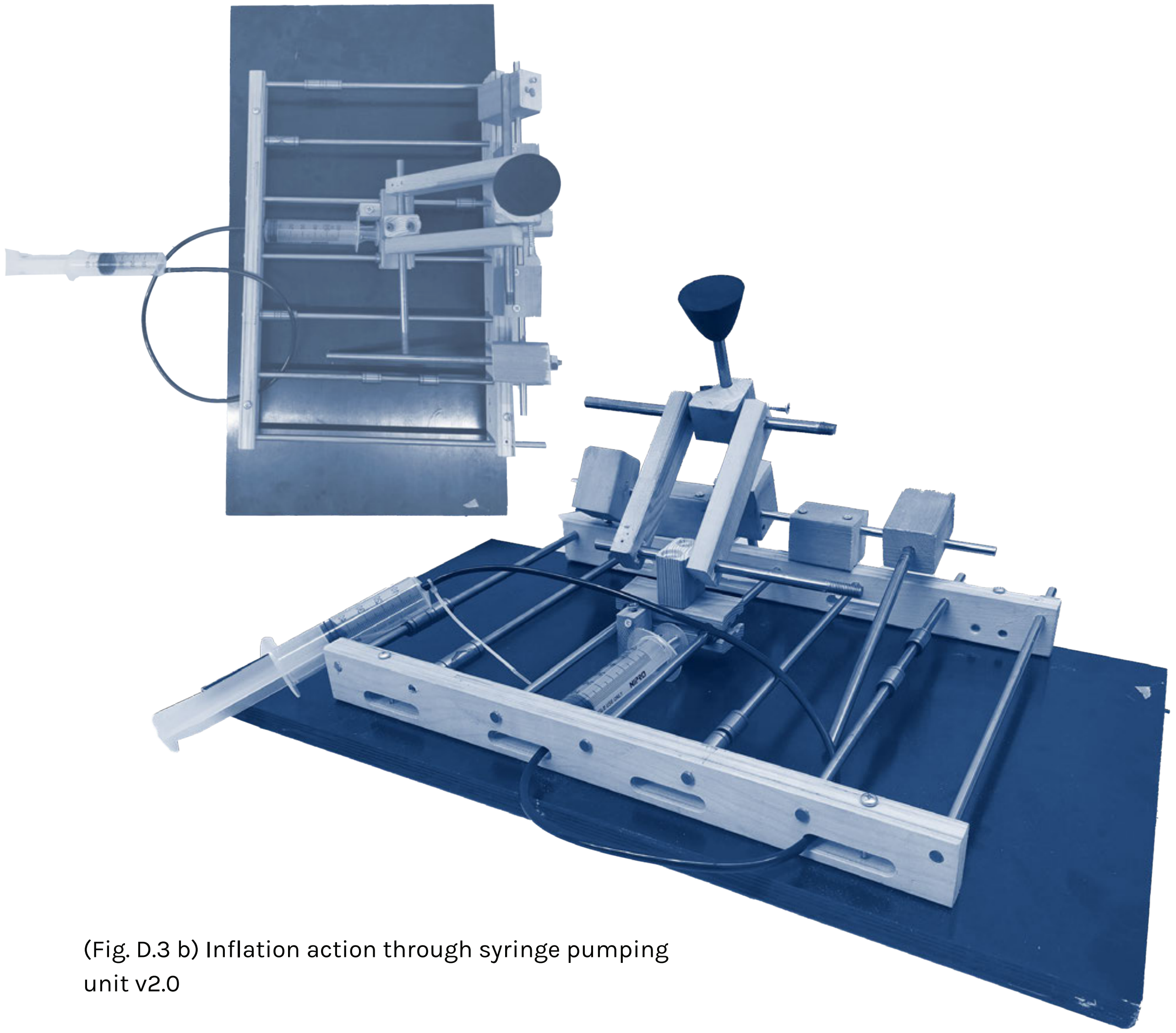
Easy to handle and access but cant control the exact volume

The LEGO pneumatic cylinders, bellow based and foot pedal based inflating systems were investigated. However, the syringe based pumping system was chosen for the next stage of design improvements primarily for their accuracy in pumping precise amounts of air, making it possible to pump air by directly placing on the table, and also creating to-and-fro pumping actions.

The syringe based inflation system was chosen as the logical next step as it was fitting well into the product roadmap in terms of making it possible to code by means of air. There is a possibility to combine multiple inflation ports, modularity and ease with which it could be inflated and deflated as well.



(Fig. D.3 a) Initial prototypes made for the syringe pumping unit



(Fig. D.3 b) Inflation action through syringe pumping unit v2.0

In order for easier inflation of multiple inflatable blocks at the same time in different sequences, lever arms were designed in such a way that they could pump air into the blocks in various ways. The lever arms reduce the effort required to make the silly stompers move in several ways.

The figure shown above illustrates the proof of concept of how syringes could be used to pump air. This functional prototype also illustrates how the to-and-fro motion could be adjusted using a lateral lead screw.

The inflation unit is fixed to the table by means of suction cups and gives the children control over how the silly stompers should move. Apart from this, this particular unit was designed with a foresight for making the stacking of individual syringe pumping blocks more modular.

D.4

reducing the frustation while connecting the blocks

Based on the observations from Design test 1 and Design test 2 (Appendix A), it can be concluded that the interconnectors previously used in research of the modular blocks of InflatiBits increases frustration in combining the modular blocks through the interconnectors. From what was observed, the cylindrical end was difficult to squeeze through inside the modular blocks.

To come up with possible alternatives, tapered ends as shown here, bistable and magnetic connectors (Lee et. al, 2016) were explored for easier attachment/detachment thereby improving the interaction

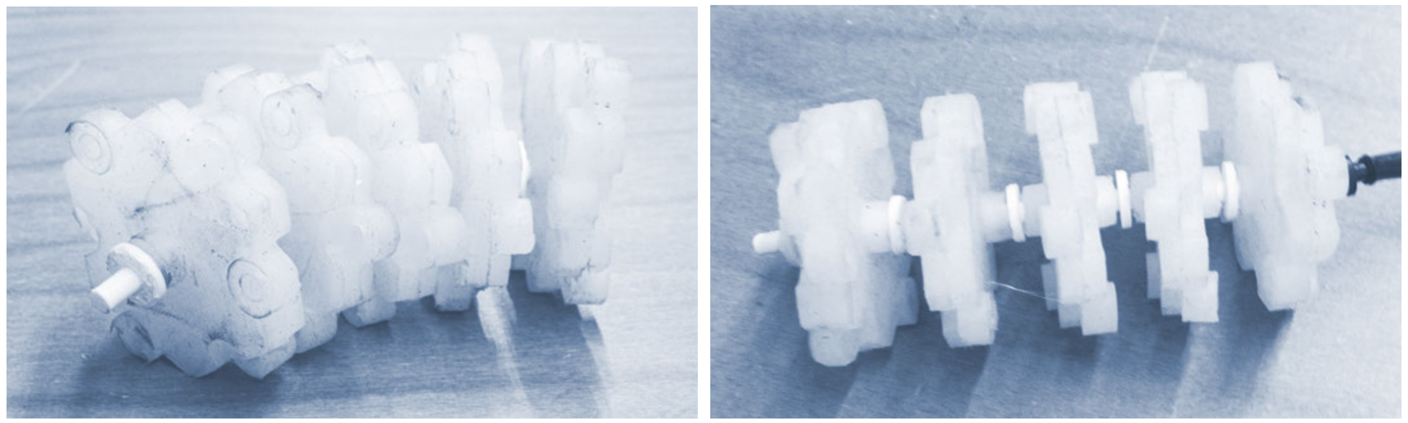


Fig. (D.4 a) Inflation action of the soft modular actuation blocks

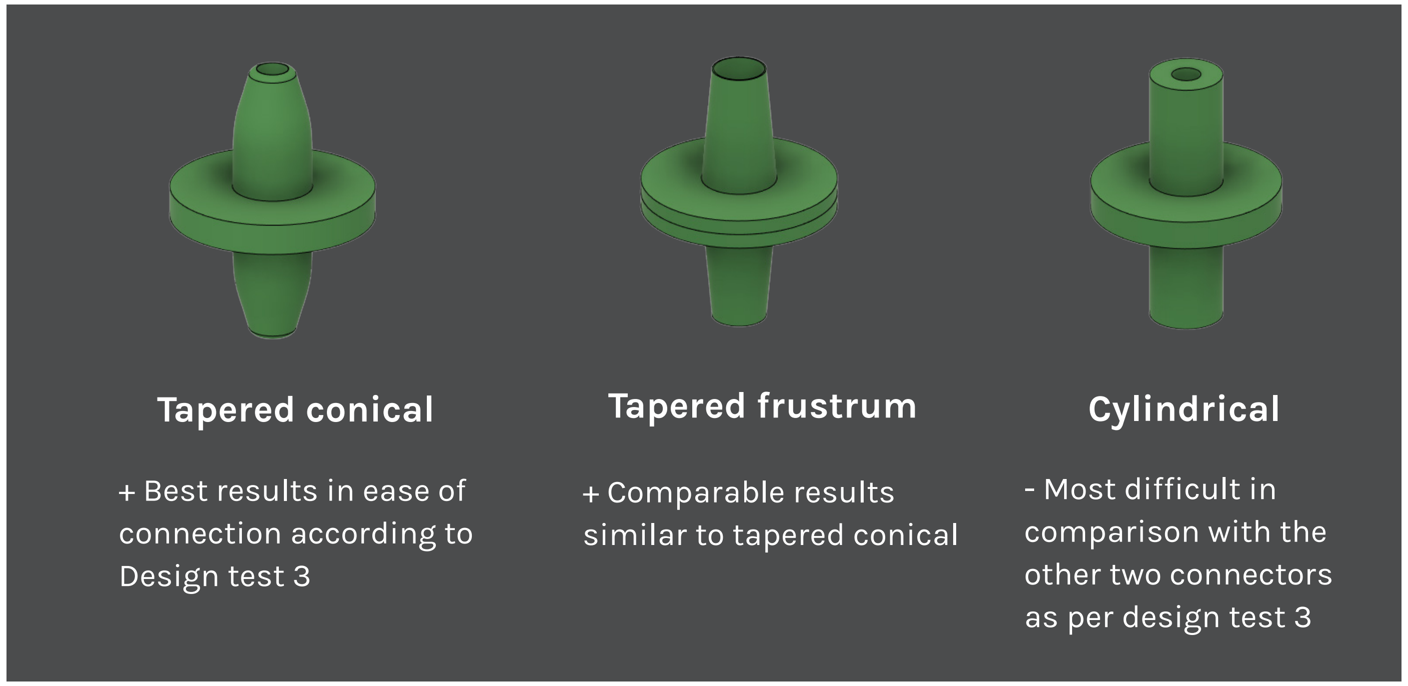


Fig. (D.4 c) Weighted criteria method for evaluating and selecting the concept for the next stage

Fig. (D.4 b) Final selected interconnector making it both easy to pull, push and also being airtight at the same time.

The tapered conical interconnector was chosen as the right interconnector for attaching the inflatable modular blocks with each other.

Apart from these three shown in the above figure which were used as probes for design test 3 (Appendix A.3), several other types of connectors were also investigated such as the bistable connectors, push-pull and screw type connectors which were used in conjunction to SoBL Blocks (Lee et al, 2016) The key disadvantage of these types of connectors are the requirement of extra pushing force to interconnect the modular blocks and therefore were not taken into consideration for testing.

All these connectors, however required customised fabrication, therefore, further investigation was carried out to ascertain off-the-shelf components which could be retrofitted for the same purpose such as quick coupling connectors consisting of O-rings to seal the joints. However, they are quite expensive, heavy and needs to be custom-designed for the application, which makes it difficult to retrofit.

For better improvement of the reversible modular connectibility, magnetic connectors were explored to redesign the inflatable blocks taking into account insights as per (Kwok et. al, 2014) Neodymium Iron-Boron ring magnets were used. To introduce the magnetic interface onto the soft actuator, the magnet of appropriate sizing was embedded taking into account the orientation of the pole.

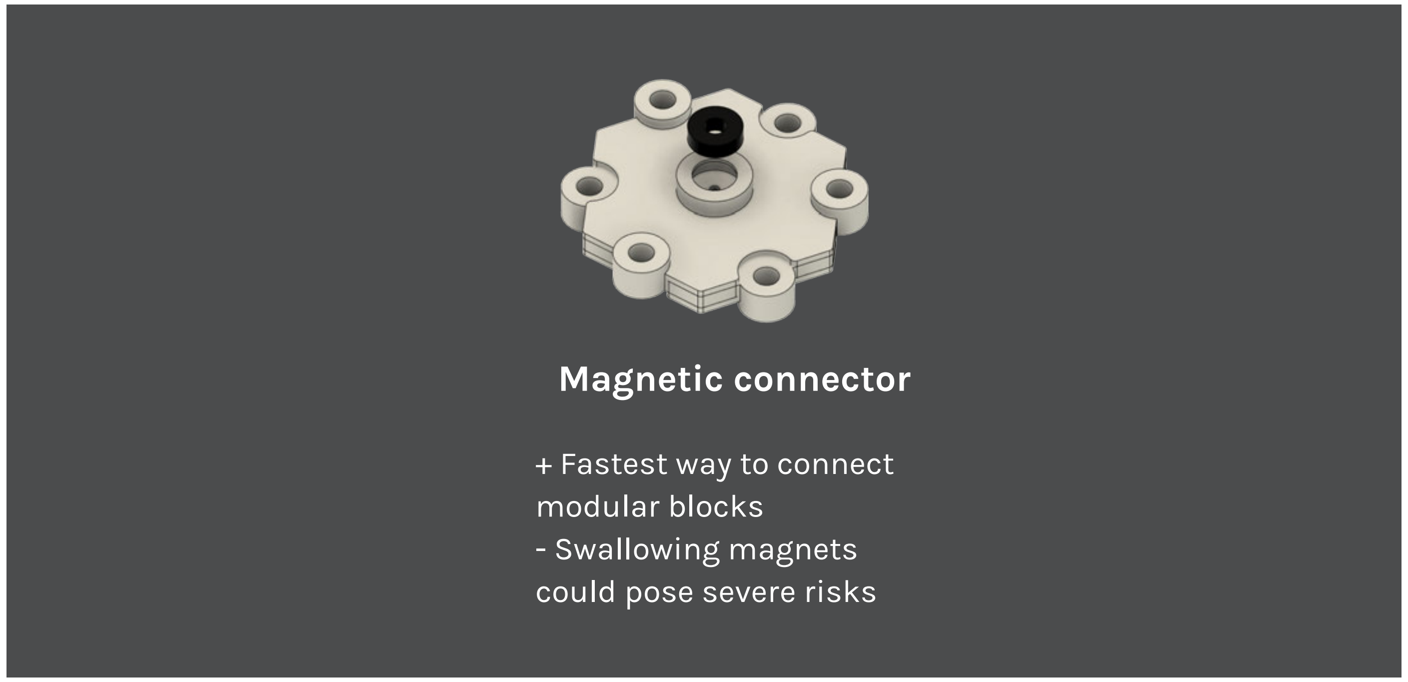
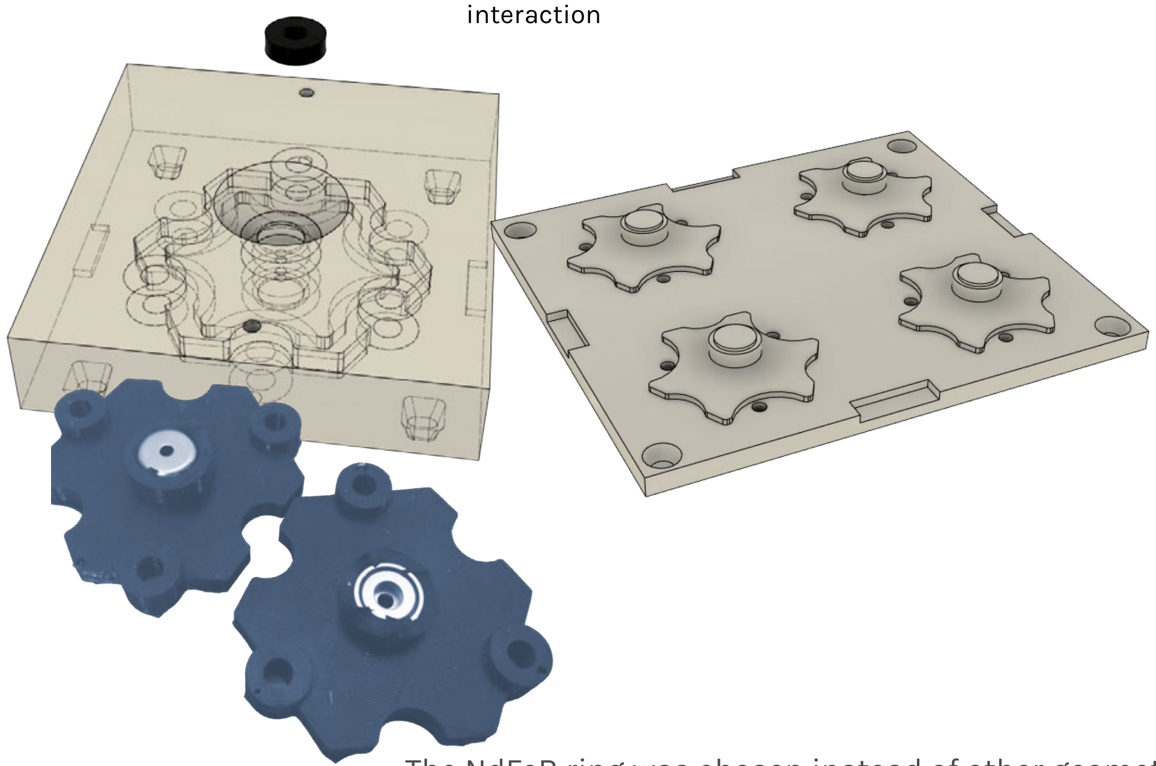


Fig. (D.4 b) Magnetic connectors for plug and play interaction



The NdFeB ring was chosen instead of other geometries as the magnet self aligns into the inner diameters of the inflatable air chamber providing a continuous conduit for transporting air through the chamber without any breaks. NdFeB also maximises the strength of the connection, while minimising the mass of the assembled device.

Custom molds were made to ensure a custom fit for the ring magnets into the inflatable blocks. However, the interconnections were not a proper fit as there was air leakage from the sides. Owing to these complications, the tapered conical interconnector shown in fig. (D.4 b) was chosen as the most appropriate and taken forward.

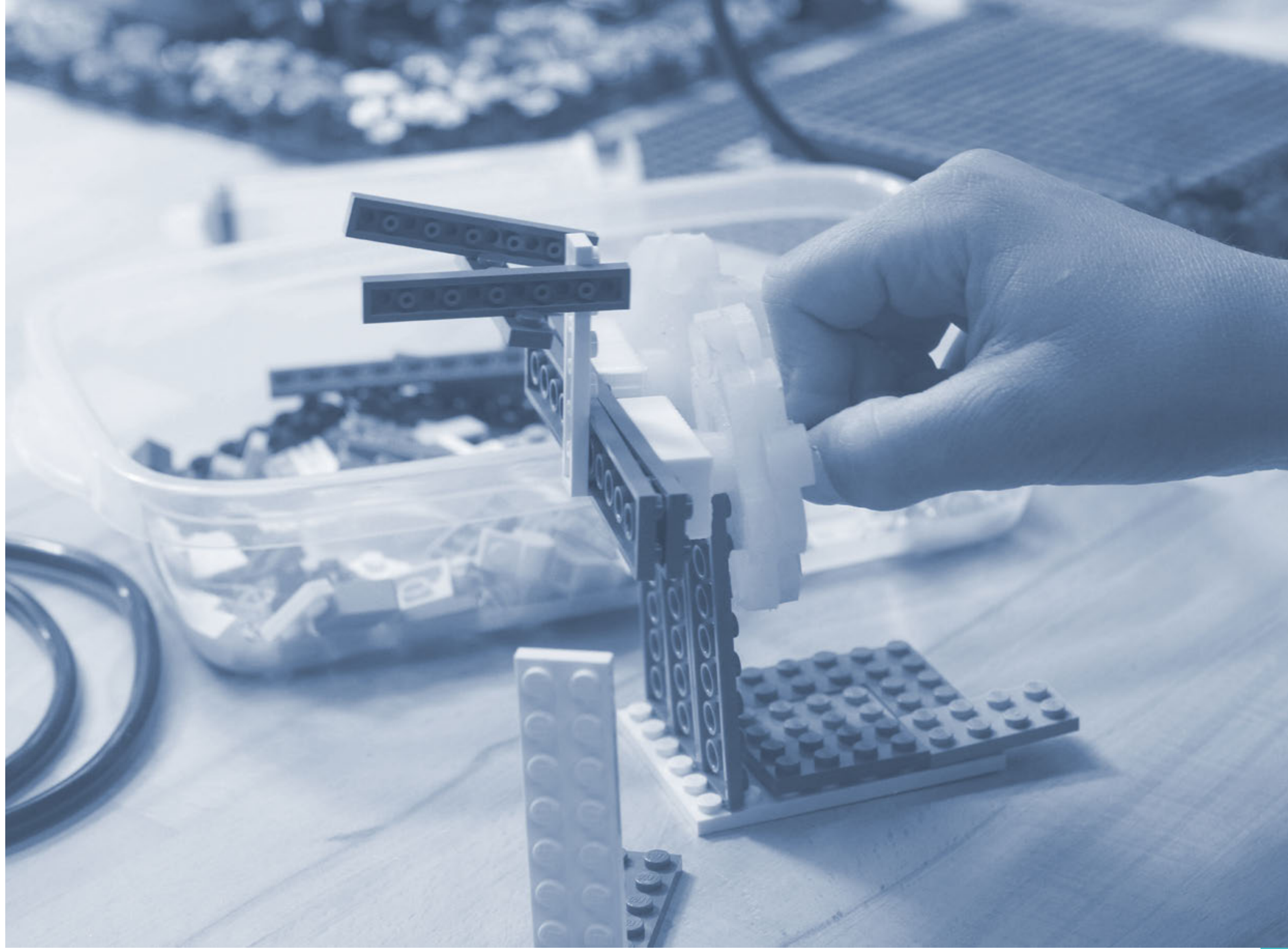


Fig. (D.6 a) How the soft modular blocks are being used in combination with the LEGO blocks

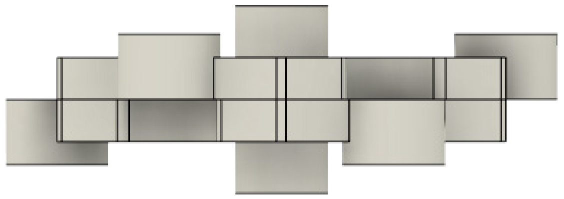
D.5

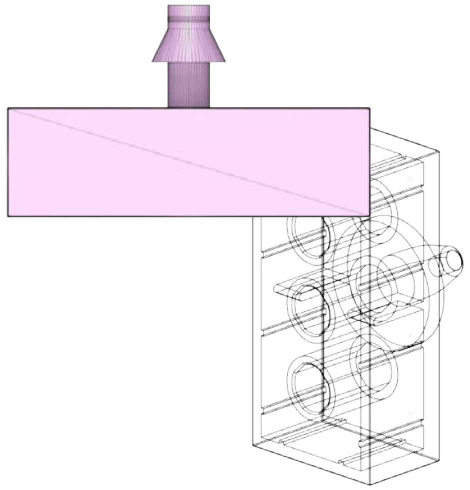
making it LEGO compatible

Introducing LEGO compatibility to these soft modular blocks provides much more versatility, and the ability to not be constrained by what is being offered by the specific toy set.

There have been a couple of research studies demonstrating certain designs of soft robotic blocks which are LEGO compatible. In Click-e-bricks, (Morin et.al, 2014) demonstrated rectilinear elastomeric bricks that has pegs and recesses.

Another variant of the LEGO compatible blocks are the Soft LEGO blocks (Lee et. al 2016). Here, bottom up design has been explored through the design of pneumatically inflatable soft bricks, flexible bricks and channel bricks.





In the previous examples, soft LEGO like blocks which have pegs and recesses are shown. However, for this application of soft inflatable blocks which are compatible with the LEGO ecosystem, connectors are designed as shown here on the left. The tapered conical shape is based on the conclusions from (Appendix A) for easier plug and play experience.

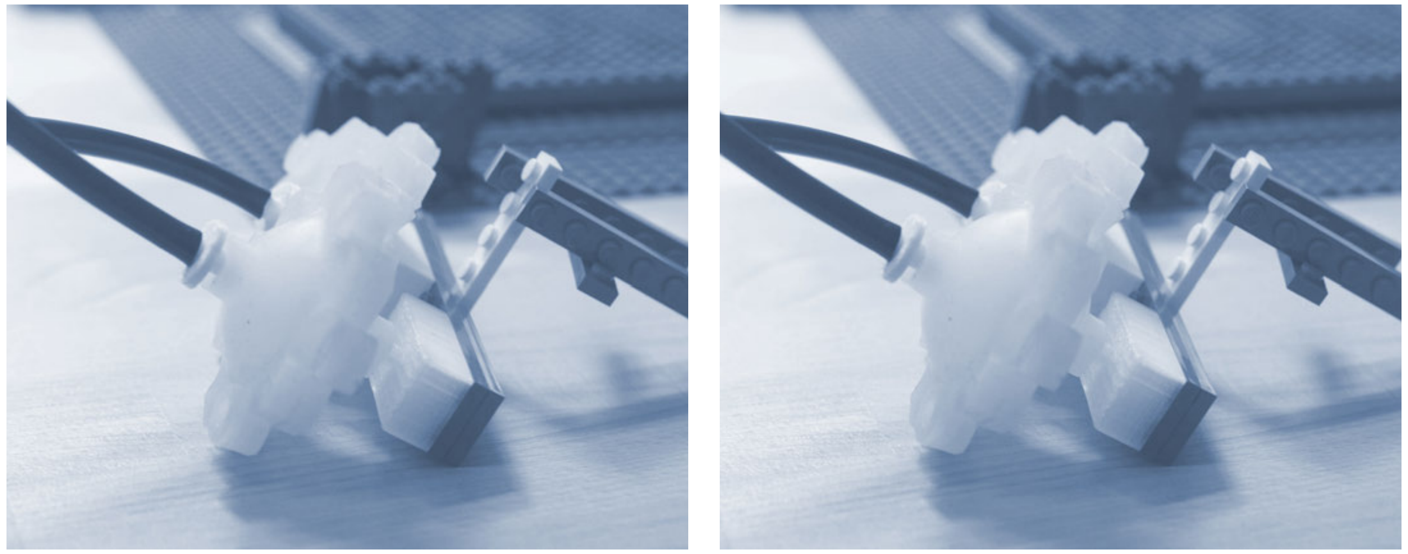
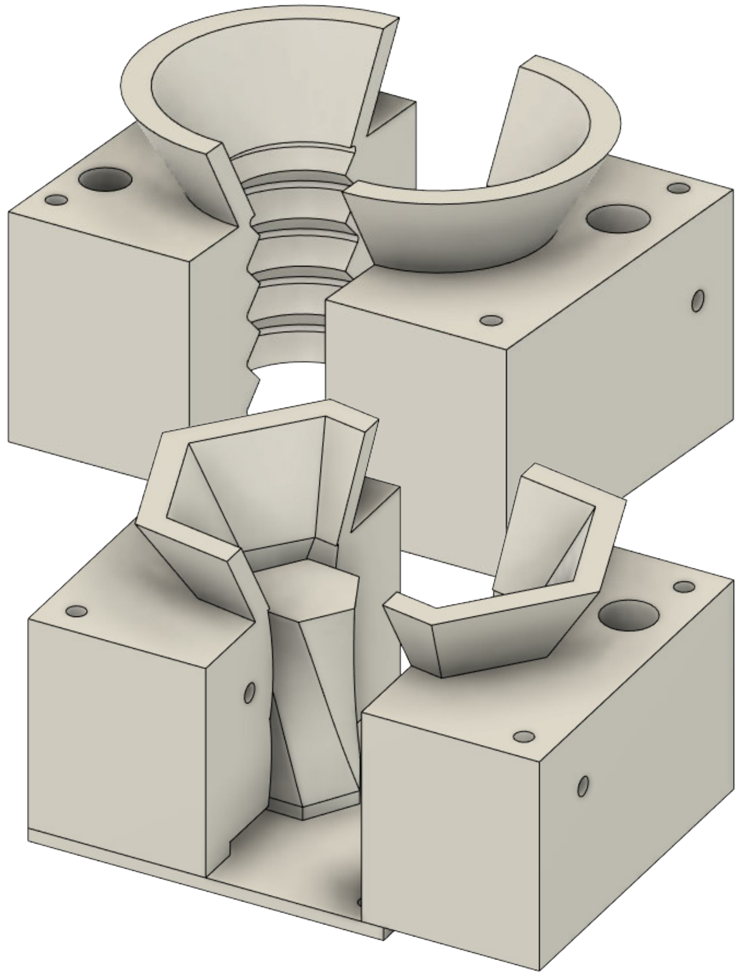


Fig. (D.5 b) Example of how the soft actuator units are connected to the LEGO system

D.6

how to integrate sensors into the soft modular blocks

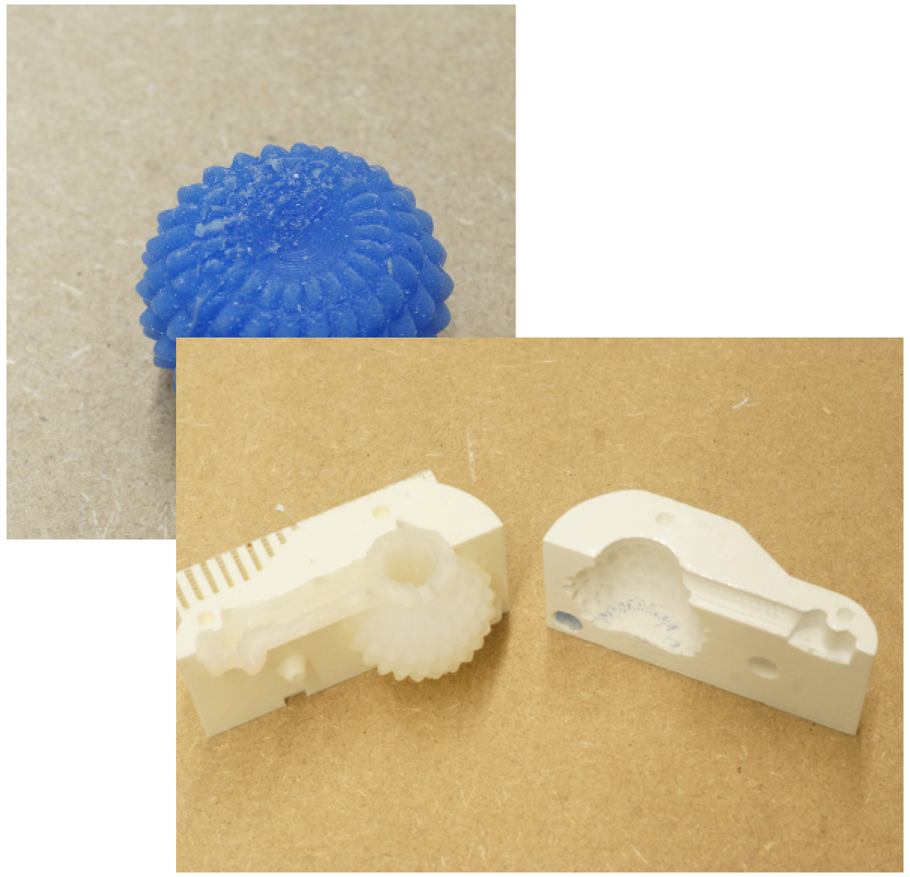
There were several experimental directions explored for understanding how soft sensors could be integrated with the soft actuators. In this iteration, push, pull and twist sensors were developed with the objective of performing more ways of human robot interaction.



Molds for push, pull and twist sensors were designed accordingly. The inlet point was significantly higher and larger than the top contact surface to prevent air bubble formation.

The air pressure sensors were placed at the bottom edge cap for adequate pressure sensing of the gestures.

The max pressure range of the touch gestures are detected to choose the required sensors for the pressure detection.



Apart form the push/pull and twist sensors, the squeeze sensors are also designed according to the figure given here.

D.7

silicone molding

There were some issues in pushing the silicone through the syringe to pump into the mold. This was eventually managed by tuning the thickness of the mold walls (the empty space which was supposed to be filled by the liquid mixture). The thickness value was adjusted to force the silicone into the mold and at the same time rendering it functional for the application.

In order to make it easier to pour the mixture into smaller mold walls, silicone thinner was added to the mixture. Although the final hardness was a bit lower than the initial mixture (Dragon skin shore A 30), the mixture will be much lower viscosity, resulting in an easier insertion into the mold.

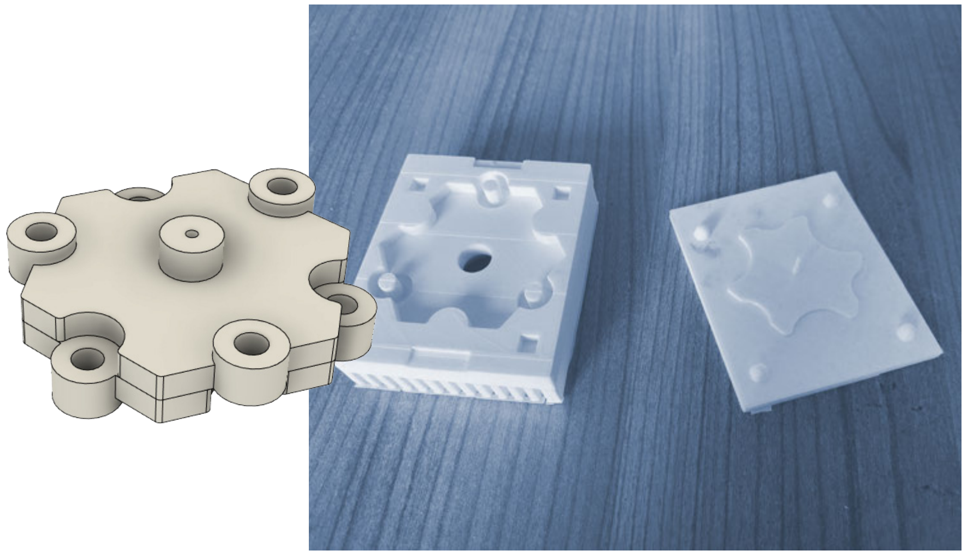
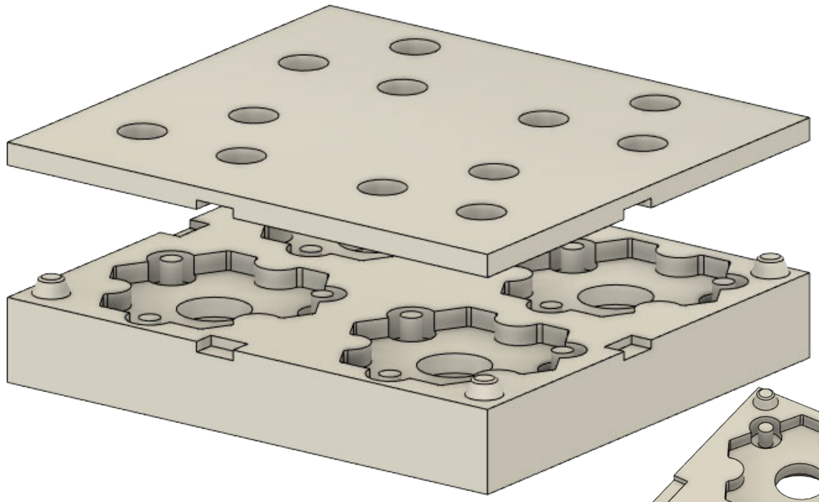
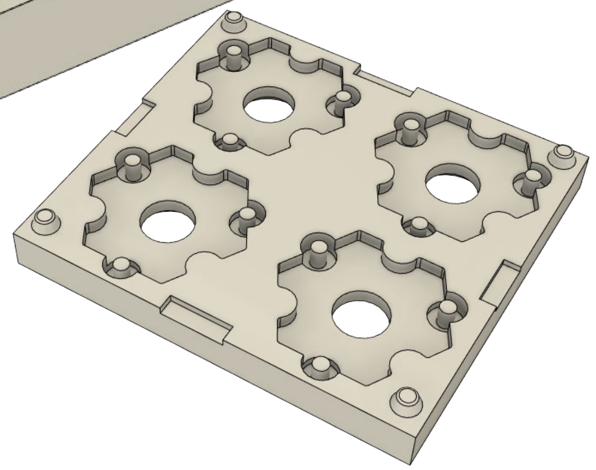


Fig. (D.7 a) Cast for the two part mold of the inflatable blocks.



A two part mold was later iterated upon to make it more efficient to cast multiple blocks at the same time.



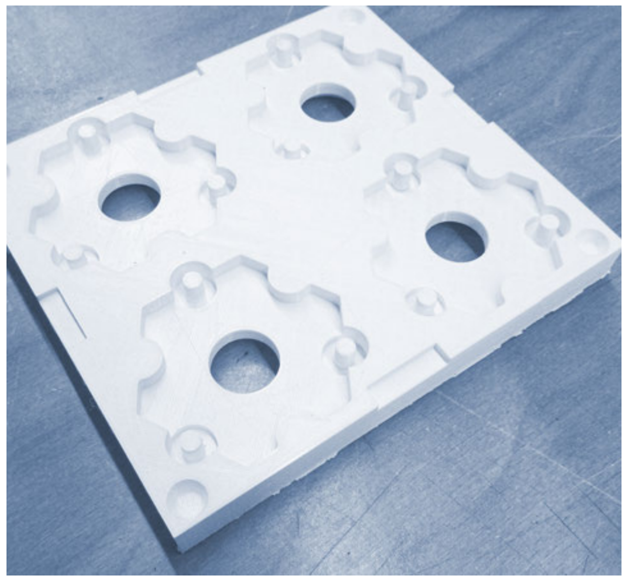


Fig. (D.7 b) As the process of casting and fabrication was quite time consuming, a four-in-one mold was created to increase the speed of completion in fabricating multiple blocks at the same time.

appendix E

miscellaneous

E.1

reflection

verbal prototyping

It was very difficult in the beginning to explain what I was exactly doing, or what problem I was solving. The fuzzy front end was really fuzzy and while navigating this space, what really helped in articulating the exact problem definition or the solution in itself was the conversations which I had with my peers. In these conversations I had to explain what I was doing in a short and succinct way. What I now realise was that this was, helping me articulate my thoughts in a clearer manner. In this sense, verbal prototyping helped me articulate and refine the explanation of what the problem is, and how the solution solves it.

planning

In terms of planning, the global gantt and the detailed gantt with the step by step breakdown of tasks and activities, especially milestones for every week helped me focus on the most important and urgent tasks. In retrospect, the week is a better unit of planning as there are a lot of uncertainties, and it is becoming much more easier to plan for the week than a step-by-step breakdown of activities for the day, which in most cases doesn't go as per plan.

being receptive to criticism

The monthly meetings with the chair and mentors really helped me stay grounded with my approach and find my north star. There were moments where I got into some confusing boundaries. However, communicating my progress to the experts helped me overcome my design fixation. To be as receptive to feedback as possible, recording the Zoom meetings, rewinding them and recalling instances for improvement helped refine this report further.

COVID based planning

I started with my graduation thesis right at the moment when the lockdown had started in the Netherlands, it was initially difficult to find the flow, as I was quite used to working in the faculty and so on, and it was difficult to mentally accept my own home as a workspace leading to a lot of lethargy and sluggishness. In addition to this, there were a lot of uncertainties with regards to the plan for the design tests which I wanted to conduct on a timely interval to guide the design process.

Due to this, the planning of the design tests got reshuffled and I had to quickly adapt and pounce on any opportunity I got specifically for the tests which were already so difficult to organise during these times. For getting more participants, a smart move carried out was to conduct it with siblings, as there were no specific social distancing rules between the siblings. On reflection, I feel contempt with the number of participants that I tested this product with, with a fair measure of both boys and girls to get more insights.

Apart from the whole designing process itself, I had to learn how to make molds and cast soft actuators which had a steep learning curve. The planning for learning how to build with these soft actuators was not exactly considered in the initial planning. During mid-term, there was a reflection which guided in making a more concrete COVID-proof plan to execute the thesis in time.

sunk cost fallacy

Reflecting on the RtD approach itself, I realised that I spent more time in improving a prototype just because I have already put a lot of effort into it. In hindsight, I feel that the embodiment and prototyping phase should have been pushed a bit late, and the initial month should solely be drawn towards research so that there is no sunk cost fallacy. However, there is a trade-off as less time spent in the initial phase with regards to prototyping means more time which should be spent later in learning how to prototype for soft robotics.

There were two revisions made to the gantt chart, and the planning was adjusted. Part of the reason behind this was the setup of a very ambitious milestone of designing a product, and also conducting workshops for children with the product. In this timescale, I was able to make a functional prototype with some concept renderings, but was not able to take it to the next step. Through the result of the four design tests conducted, the material expression of soft objects, character design and roleplay were validated. In addition, the key embodiment challenges with regards to creating the modular blocks and actuating them in itself were also successfully tested and validated.

In retrospect, the plan to have both completed, the design of the product as well as conducting workshops with children using the product seemed a bit silly.

As this thesis was more of a detailed concept development through RtD process, the future scope of this product was noted down as recommendations (Appendix 3.6) and not included in the revised plan. (Appendix C)

8 pedagogical principles

While going through the Research Through Design process, I found it difficult to go through all the listed criteria while evaluating if the probe/design/prototype was okay or not. I found the 8 key pedagogical principles which could guide any learning-through-play based activity very useful but overloading as I couldn't evaluate them on time, based on these rubrics. However, the principles were more suggestive rather than enforcing while evaluating the concepts. Not only that, they also played a major role in designing the interaction experience of the product itself to make sure that the learning outcomes were matched. Upon reflecting over my own design process, I could see that I evaluated concepts based on the most important parameters, and used the other requirements in a more suggestive sense to improve the product itself.