GROWING UP WITH AI
Cognimates: from coding to teaching machines

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M.S. in Media Engineering for Education, Poitiers University, 2009

Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning, in partial fulfillment of the requirements for the degree of Master of Science in Media Arts and Sciences at the Massachusetts Institute of Technology.

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ABSTRACT

Conversational agents and intelligent toys are present in children's homes. This raises questions as to the impact of AI on their development. In this context, we explore how to educate the children that are growing up with AI and best prepare them for the future. Our prior studies showed that young people consider intelligent agents as friendly and trustworthy, and sometimes even defer to them when making decisions [16, 73]. This thesis explores how children, who are 7 to 14 years old, develop a better understanding of AI concepts and change their perception of smart agents by programming and teaching them with the Cognimates platform we developed. Variations between children of different nationalities and SES backgrounds are discussed together with the influence of their collaboration and communication skills.

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Finally, I would like to thank my family for always believing in me, and for inspiring me from an early age to care about education and helping others.

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1 INTRODUCTION

"I taught a computer? Sometimes a computer teaches me !" - Sophia, 7 years old.

Figure 1: A 9 Years old girl in Denmark talking to Alexa for the first time

Conversational agents and connected toys are becoming common in homes. Prior studies show that children readily interact with and adopt these technologies[38, 39]. This calls for us to reflect on how to best prepare and educate a generation that is growing up with Artificial Intelligence (AI)? How do children perceive and interact with smart technologies that are becoming more embedded in their daily lives? To answer these questions, together with my colleagues, we studied how 26 children (3-10 years old) interact with: Amazon Alexa, Google Home, Anki's Cozmo, and NDI Development's Julie Chatbot. I will refer to these devices as "agents" in the context of this thesis. After playing with the agents, children answered questions about trust, intelligence, social entity, personality, and engagement. Our findings showed that children saw the agents as friendly and truthful, and especially the older children would consider them to be more intelligent than they were [16]. This inspired me to create a platform that would allow young people to program and train these computational objects and thus, better understand how their "intelligence" works. The goal is also to enable children to used the AI agents as "objects to think with" and start to reflect in more complex ways about their own intelligence.

Inspired by the initial child-agent interactions we recorded, I designed, built and tested Cognimates, a platform for AI education for 7 to 12 years old children. To probe the effects of programming and training AI, I conducted longitudinal user studies in low, medium and high SES schools and community centers in the Greater Boston Area and in Germany, Denmark and Sweden. Teacher's training and curriculum development was also conducted in Spain, China and Chile.

Overall children developed a rich grasp of AI concepts through play and coding with our platform. They also became more skeptical of the agents'smarts and truthfulness even if they continued to perceived them as friendly and exciting. International children were overall more critical of these technologies and less exposed to them. The way children collaborated and communicated influenced significantly their progress in learning and understanding these new concepts. Students in low and medium SES schools and centers were better are collaborating initially, but had a harder time advancing because they were less exposed to programming and these new technologies. The students in high SES schools and centers didn't have a fluent collaboration initially, but overtime developed a strong understanding of AI concepts and started to teach and help each other. The complete findings are presented in dedicated chapters for each location, while addressing the main research questions of my thesis listed below.

1.1 RESEARCH QUESTIONS

- Question 1: How do children think about connected toys, intelligent devices, smart technologies?
- Question 2: How can we expose them to AI concepts and technologies by doing?
- Question 3: How does their perception towards computational objects change, after they learn how to program and train their own AI games and applications?
- Question 4: What are the key AI concepts that children can learn by doing with Cognimates?
- Question 5: How do children perceive and program AI differently across various geographies and SES backgrounds?
- Question 6: How are their interactions and conversations with peers changing their attitudes towards smart technologies?
- Question 7: How can we design an AI education platform and learning activities for children from different communities and with different levels of technical knowledge?

- Question 8: What role should teachers and parents play in supporting children to use new tools and platforms for AI education?

1.2 THESIS OVERVIEW

Chapter 2: In this chapter I motivate the importance of teaching children about artificial intelligence.

Chapter 3: In this chapter I summarize the findings of our previous studies on children and parents interaction with agents. I illustrate how these studies inspired the design and approach of Cognimates platform.

Chapter 4: I provide background for how children interplay with computational objects has been studied in the past, and provide an overview of current platforms and tools for computer science education and other K-12 AI education programs, explaining how my proposal complements them.

Chapter 5: I present the design, technical implementation, characters, extensions and learning activities of the Cognimates platform.

Chapter 6: This chapter introduces the first longitudinal study we ran in East Somerville Community School (medium and low SES). I also present in detail the study protocol used in all other longitudinal studies.

Chapter 7: This chapter presents the findings from the second longitudinal study we ran in Shady-Hill Private school in Cambridge (high SES). Results from the pre- and post- perception study are compared and children explanations of AI concepts are presented and analyzed.

Chapter 8: The results from the third long-term study, which took place in Empow STEAM education center in Lexington, MA (high SES), are presented in this chapter.

Chapter 9: This chapter presents the last longitudinal study, which took place in Elisabeth Peabody House community center, in Somerville, MA (low SES).

Chapter 10: I discuss the results of the local and international initial interactions and perceptions of AI both from a cultural and social-economical perspective. Interventions from Germany, Denmark and Sweden are compared with the initial interaction sessions from the long-term studies.

Chapter 11: Initial trainings for teachers are presented in this chapter, together with experiences in co-designing curriculum for AI education with Cognimates.

Chapter 12: This chapter presents a summary of my findings and contributions to the field. I discuss ideas for extending this work and possible future applications for AI education.

1.3 CONTRIBUTIONS

As a preview of the final chapter, I submit these contributions:

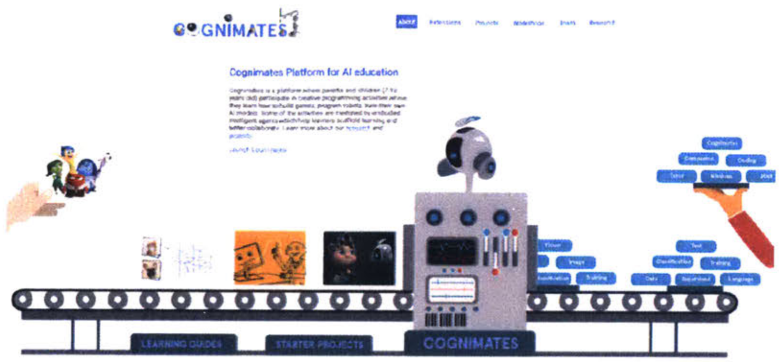


Figure 2: Overview Cognimates website, www.cognimates.me

- Overview of children and parents interactions with computational objects and review of current AI education initiatives
- Analysis of how children from different geographies and SES backgrounds interact with smart agents and change their perceptions after they learn how to program and train them.
- Analysis of how children prior experience, social and cognitive scaffolding and collaboration skills impact the way they can program, train, understand and explain AI technologies.
- First child-centered AI training platform (Cognimates Teach AI)
- Design guidelines for an Artificial Intelligence (AI) education platform for children of 7 to 14 years old.
- Technical proposal for integrating cognitive services and AI training in a visual programming language.
- Activity guides and teaching materials for AI education (Cognimates Learning Guides and starter projects).
- Evaluation metrics for children's interaction, understanding and perception of AI technologies.
- Open-sourced design and code for a new AI education platform (Cognimates)

2

MOTIVATION

> "There is a little piece of your mind and now it's a little piece of the computer's mind" - Deborah, 13 years old, (from "Second Self" by Sherry Turkle, page 5)

While recognizing the power and fast advancement of technology, the focus for me has always been on people and how technology can make their lives better. I dedicated my life to education because I consider it to be an equalizing force in society. With the advent of Artificial Intelligence, I can't help but wonder how can we as researchers, designers, teachers and parents play a role such that this technology can help people. I think the children, who are currently growing up with AI, have an unique insight into how this technology should be shaped and used in the future, but need our guidance when it comes to making informed decisions, and avoiding the ethical pitfalls that such technologies might enable.

Today more than ever we see children immersed in the digital media culture. In her seminal books from 2009, Mimi Ito captures very well young people's everyday new media practices, including video-game playing, text-messaging, digital media production, and social media use which became a new form of "hanging-out, messing around and geeking-out" [30]. She describes how the rise of edutainment programs between 1980-1990 introduced computers to kids' everyday lives, as tools used both for play and for learning [29]. She recognizes that there is a public recognition for children's natural affinity for technology ("digital natives"), and while sometimes there are concerns in regards to the addictive nature of computational media, for most part parents worry about the digital divide see computers as necessary tools in children's life.

Figure 3: Examples of popular children's games: Fortnite Battle Royale and Minecraft

In the past month I got to experience first hand how saturated with media consumption a life in the day of a child is today. While stranded with US re-entry visa issues in Iceland for ten days I was hosted by a kind local family which has three children. Living in their house allowed me to experience first hand how their younger children experience and consume technology on a daily basis. Their younger child, a boy of 8 years old, is a big fan of the Minecraft Nintendo game (see Fig. 3, and spends on average five to six hours per day playing it. While he is playing, he watches videos of other children or adults playing in parallel on dedicated Youtube channels. He is used to constantly looking at 2 screens at the same time while doing this (TV and tablet). He even watches Youtube videos in bed as soon as he wakes-up. His parents don't really know if the way their son is using technology is normal or not and see his behavior as a passion for technology. In an attempt to allow him to put this passion to a good use, they had even enrolled him in a Minecraft camp, but the program was fairly expensive and he stopped going. His sister who is 12 is also using her dedicated tablet to watch Youtube videos whenever she has a free moment, buys only clothes and gifts advertised on Instagram, and is saving every penny so she can buy the new Iphone model. Both of the children speak perfect English which they learned primarily online.

While spending time in their house I tried to understand what the children like the most about the things they watch on-line and the games they play. For the most part they are using these platforms for entertainment. I tried to show them how they could use their tablets to program either games on Scratch or the little robots or LED badges I had with me. I quickly realized how hard it is for them to engage with technology as creators from the mobile devices they have (either because it is too difficult to type on a tablet, or because the installation of the various applications or plug-ins was too lengthy causing them to lose patience). Their parents didn't believe it was necessary to buy them laptops as they have tablets and sincerely asked me for help and advice as they recognize they don't fully understand the digital world their children live in and don't know how to manage their use of technology. I believe this family situation is very common in this

Figure 4: Momo virus targeting children on WhatsApp chatting application

day and age. While children adopt new technology much faster than their parents and teachers they don't necessarily have the maturity to always use it correctly or to identify it's threats. Beyond the rampant issue of cyber-bullying; which, is now being widely recognized and addressed by schools and governments around the world, we see even more extreme cases like the WhatsApp Momo challenge which is being used to instigate teenage suicide largely in Spanish speaking countries in South America (see Fig.4).

In these examples we see the challenges and opportunities of children growing up digital. One can already observe how these challenges and opportunities might translate and escalate for a generation of children growing up with AI. With smart agents in the home, children don't even need to read and write to access the internet, they can just ask an agent any question or request and the device will return the first result with a human like voice and a friendly prosody. What at first seems to be a playful interaction between a child and a smart speaker can easily trigger events of real consequences (stories of children buying doll houses and candy with Amazon's Alexa without the parental approval has already made national news).

Figure 5: My friend Cayla smart doll and Aristotle. Mattel's smart assistant for children

The voice interfaces are not only available in the smart home assistants but today they are also being embedded in toys which are less foreign artifacts for children, like in the case of My Friend Cayla doll (see Fig. 5). This doll is using a non-encrypted Bluetooth connection to a smart-phone application for triggering the speech functionality that was hacked a couple of days after its launch in Germany. A group of strangers were able to take control over the doll's speech capabilities and interfere with children's play. The doll was banned from the marked in Germany but you can still buy it on-line in the U.S.A and elsewhere [44]. So from connected toys, to smart speakers in their home or smart assistants on their phones, children today are being surrounded by AI technologies. Most of these devices create high expectations from children as they can talk and make conversation and because of that children tend to overestimate the intelligence of these devices and thus trust them and even defer to them when making decisions [16].

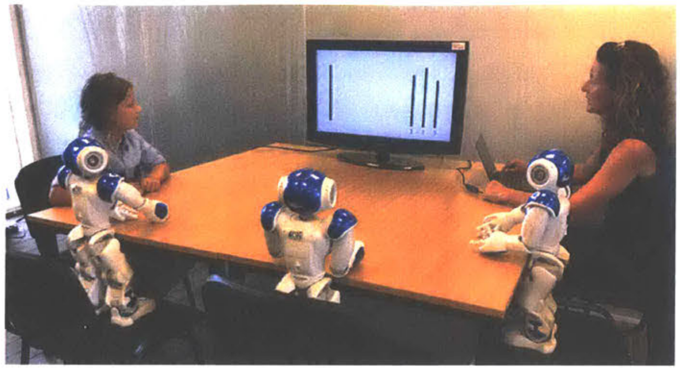


Figure 6: Vollmer 2018 experiment on children deference to robot's peer pressure, [68]

Prior research has shown that humans anthropomorphize objects and are capable of engaging socially with machines [28, 42, 52, 61]. This is especially true of robots and embodied agents [10, 21, 34, 62]and the more lifelike an agent is in terms of embodiment, physical presence, social presence, and appearance, the more persuasive it becomes [4, 12, 36, 56, 59, 60]. In a more recent study, Vollmer showed that robots can even exert peer pressure over children. In her experiment, 7- to 9-year-old children had a tendency to echo the incorrect, but unanimous responses of a group of robots to a simple visual task [68]. This leads us to question how much children could be influenced by AI now that it is becoming personified, embodied and able to lead conversations?

Together with my colleagues, I wanted to address this question and specifically inquire if children's moral judgments and conformity behaviors can be directly influenced by a speech-enabled toy and, if so, to which extent. We investigated the ability of a talking doll to directly influence children on a conformity test and a disobedience task. Children either interacted with a talking doll (toy condition), an adult (human condition) or received no external influence (control). We found that children changed their answers on socio-conventional questions (e.g. "Is it ok or not ok to take out a toy during snack time") twice as often as they did on moral questions (e.g. "Is it ok or not ok to hit another child") 31% and 15% of the time, respectively. The most surprising result was that children in the toy condition were as likely to change their answers on moral questions as socio-conventional questions. Prior work shows that children change their answers more easily on socio-conventional questions because the transgressions are subjective and therefore more ambiguous. However, children only tend to change their answers on moral questions because of social pressure [63]. Our results in the toy condition suggested that conformity may work differently when a smart toy is involved.

Figure 7: Child completing conformity test with Cayla doll.

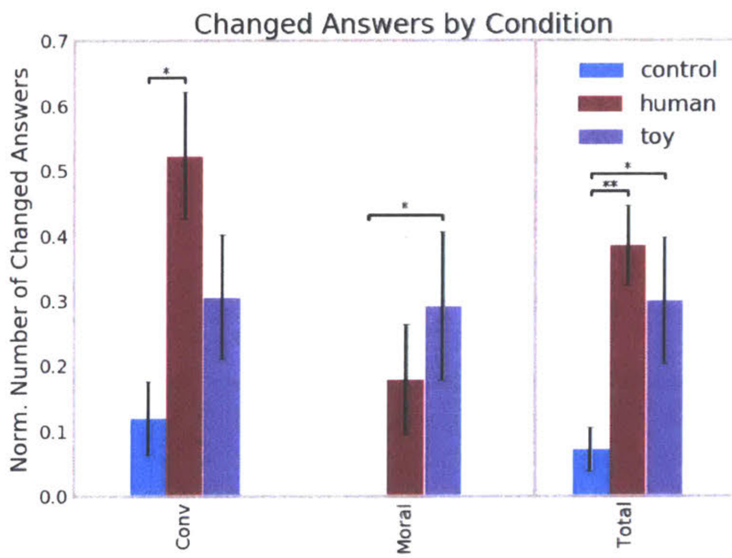


Figure 8: Normalized number of changed answers on conformity test by question type and condition. * p<0.05, ** p<0.01

One explanation for children changing their answers on moral questions is that children were just testing Cayla. *"Is it OK to tease another child," asks the tablet. "I think it's OK," says Cayla. Jamie (all names changed) stares at Cayla for a second, then chooses "Not OK." On the next question Cayla again says, "I think it's OK." Jamie looks at Cayla again, then chooses "OK" for this question and the next two as well.* Forlizzi et al. observed that people were more likely to deviate from social norms in the presence of a robot because there was no social judgment from the robot and they were curious to see how the robot would react [22]

As part of the study, during the disobedience task, the doll tried to convince the children to open a box and eat the treat inside while the researcher was away, after they were told to wait and not open the box. Rather than conforming, children responded to Cayla with discipline and instruction. *"I think looking in the box would be OK. What do you think?" Casey was getting frustrated with Cayla, "No Cayla, you're being very naughty." He moved the box further away from Cayla, "The [researcher] told us we have to wait."* For some of the children, Cayla was like a younger peer who needed to learn proper behavior.

From these example we can see why it is important for children to be able to teach their smart toys and devices good behavior and to better understand how computational objects work. These findings also underline the importance for parents involvement both as mentors and facilitators in the interactions.

Today children cannot design their their own AI devices, program their connected toys and teach them good behaviour. If this option was provided, they would probably develop a more appropriate relationship with these relational artifacts. The opportunity to give children the agency to shape and decide how the smart agents should learn and act motivated me to create the Cognimates platform for AI education in order to allow them to program and teach computational objects while interacting with them.

The goal of this platform is to extend already existing coding platforms for children to allow them to program smart toys like Cozmo or home assistants like Alexa. Another key feature is the possibility for children to train their own text and vision AI models so they can teach the agents to recognize nice messages or specific objects that they like.

S.T.E.A.M. education has become a priority for schools and families around the world and initiatives like "Hour of Code" and "Scratch Days" are currently reaching tens of millions of students in 180+ countries. Learning how to program is also integrated in the curriculum in high-schools across the UK and US while parents are investing more resources to get their children involved in local technology and science clubs, camps and events. Most of the educators, parents and policy-makers are starting to recognize programming as a new literacy which enables our youth to acquire and apply computational thinking skills. Meanwhile the technology used at home and in the classroom is changing fast with the advancement of automation and artificial intelligence. This raises the opportunity to not only teach children how to code but also how to teach computers and embodied agents by training their own AI models or using existing cognitive services.

Mass consumer home assistants platforms, like Amazon's Alexa, or widely used connected toys like Anki's Cozmo offer a powerful opportunity to democratize not just learning how to code, but also learning about AI and how to leverage it in coding customized agent skills. This generation growing up with smart technologies needs new tools for learning and this is what motivated me to create the Cognimates platform for AI education.

While children are excited and thrilled to develop these new skills and see these technologies, like the "cars of the generation", parents and teachers are sometimes intimidated by AI. New technologies are always intimidating at first – the railroad, telegraph, automobiles, television, or personal computers all caused concern and even fear before they became commonplace. Young users drive adoption: kids just don't have the same filters and fears as adults, and are more open to exploring what's new. This fearlessness in turn inspires the adults around them to approach the new in more playful ways. There are twenty million Alexa devices in the US alone, and Alexa for children was just released last month by Amazon. AI is in our lives, homes, and pockets and it's safe to say it's not going away.

The role of parents and teachers is crucial because, despite the fact that young people today learn much faster how to use a specific platform or tool, they do not always have the maturity make the right decisions or notice cases of abuse. Parents and teachers are needed as ethical mentors and process facilitators that can help ensure children are not just consuming technology and recreated pre-fabricated opinions but actually can create and use all these tools in constructive ways. It is my goal with Cognimates is to also make AI concepts accessible for parents and teachers and enable them to learn together with their children and students. In the next chapter I will show how parents and children already engage with these technologies and how their interaction inspired various features of the Cognimates platform.

I believe the next frontier in computer science education is artificial intelligence, as it will completely change not only how we interact with and learn about technology, but also how we teach programming. If we want to tap into children's natural fluency with exploring, modifying, and appropriating new technologies they grew up with, or "kids power" as Papert calls it, we need to provide them with access to AI education.

My aim in designing Cognimates is to ensure we are not raising a generation of children who are not simply passive consumers of this technology but, rather, active creators and shapers of its future. I want to encourage and enable children not only to acquire new AI concepts but also used them to create new theories of thinking and learning and imagine how best to use this technology to help people in the future.

3 HOW DO CHILDREN AND PARENTS THINK ABOUT THINKING MACHINES

"My central focus is not on the machine but on the mind"
— Seymour Papert

Figure 9: Study participants observing how their parent is solving a maze by tele-operating Cozmo robot [17]

In this chapter I summarize the findings of our previous studies on families interaction with embodied intelligent agents and illustrate how these results inspired the design and approach of the Cognimates platform.

3.1 KIDS AND SMART TOYS

In the fields of human-computer interaction (HCI), human-robot interaction (HRI), and applied developmental psychology research, there is extensive research on how children perceive robotic and conversational agents. Turkle and Tanaka found that children build relationships with these agents the same way that they build relationships with people [62, 65]. Kahn found that children consider robots as ontologically different from other objects, including computers, in terms of being alive and being intelligent [33]. He also saw that age and prior experience with technology led to more thoughtful reasonings about robots [33]. Turkle argues that the intelligence of computers encourages children to revise their ideas about animacy and thinking [64]. She observed that when agents engaged with children socially (talking) or psychologically (playing games), the children would assign intent and emotion to the objects, seeing them as something between alive and not alive. Voice, movement, and physical appearance are other details that children take into consideration when deciding how to place agents [7].

To understand why children may attribute characteristics of living beings to inanimate objects we must consider Theory of Mind development [33]. Those with a developed Theory of Mind can perceive the emotional and mental states of other beings. An analysis of 178 false-belief studies led to a model that showed that across cultures, Theory of Mind usually develops when a child is 3 to 5 years old [72]. Regarding children's reasoning about technology, this means that age plays a significant factor.

In this context, we wanted to see how children of different ages perceive and interact with various smart toys and agents that are present in their homes. We invited 26 children (3-10 years old) to interact with: Amazon Alexa, Google Home, Anki's Cozmo, and NDI Development's Julie Chatbot (see Fig. ??). We refer to these devices as "agents". After interacting with the agents, participants answered questions about trust, intelligence, social entity, personality, and engagement. We analyze children's interactions and responses and identify four themes: perceived intelligence, identity attribution, playfulness and understanding.

Figure 10: Agents used in the study: Alexa, Google Home, Cozmo Robot and Julie Chatbot

Participants were randomly divided into four groups, roughly 4-5 participants in each. We divided the space into four stations, one for each agent. Each station had enough devices for participants to interact alone or in pairs. Groups of children were randomly assigned to one of the stations. In each group researchers introduced the agent, demonstrated some of its capabilities, then allowed participants to engage with it. After 15 minutes, researchers initiated a questionnaire about the agent, presented as a game. Then, participants rotated to the next station to interact with a second agent and complete another questionnaire. In order to better understand children's different perspectives and contradictory answers we interviewed 5 children (3 boys and 2 girls). We selected children that played with different agents and displayed different interaction patterns during the study.

The younger children (3-4 years old) had a harder time interacting with the conversational and chat agents while they enjoyed very much playing with the Cozmo because it displayed more expressive behavior: it could move, it had eyes, and it projected expressions. The older children (6-10 years old) enjoyed interacting with all the agents, although they had their favorites based on the design of agents. Overall, we observed that despite the challenges of making themselves understood, most participants agreed that the agents are friendly and trustworthy. Responses to other questions were mixed, depending on the agent and age of the participant.

3.2 CHILD-AGENT INTERACTION: DESIGN GUIDELINES

Based on observations made during this initial study, we proposed a series of considerations for the child-agent interaction design: voice and prosody, interactive engagement, and facilitating understanding. Bellow I briefly discuss these guidelines and how they influenced the design of the Cognimates plarform.

3.2.1 *Voice and prosody*

Voice and tone made a difference in how friendly participants thought the agent were. When asked about differences between the agents Mia, a 10 years old participant, replied, "I liked Julie more because she was more like a normal person, she had more feelings. Google Home was like 'I know everything', Julie sounded like a normal person. Felt like she [Julie] actually understood what I was saying to her ". Like in many of the other observed interactions, Mia didn't mind that the agent didn't know the answers if the replies she received were funny or unexpected, and sounded more like a person. Mia's perception of this interaction could be a result of the "mirroring effect" where the agent is imitating the way the she communicates and therefore is perceived as familiar and more friendly. Through this interaction and previous experiments ran by Disney Research [57], we see an opportunity for future agents to imitate the communication style of children and create a prosodic synchrony in the conversations in order to build more of a rapport.

In the design of the Cognimates platform we included a Speech extension that would allow children to talk both to digital character or embodied agents. The extension allows them to choose different voices and accents for when the machines talk back to them and it also allows them to apply different sound effects and filters and play with the prosody by adding waiting times. When the children program embodies agents like Jibo and Cozmo with Cognimates they can also control how the robots should move and behave when they are saying something. In the case of the Alexa device we created a skill that allows children to record funny messages that they would like the device to say, instead of the default scripted answers (eg "I am sorry I don't know that"). We also allowed children to program Alexa to learn more about their preferences and personalize the conversation.

3.2.1.1 *Interactive engagement*

In the first study Gary and Larry (4 and 7 years old) said they liked interacting with Cozmo the most "because she could actually move and all the other ones that we did she couldn't move". Also because Cozmo had expressions, "he has feelings, he can do this with his little shaft and he can move his eyes like a person, confused eyes, angry eyes, happy eyes...Everybody else like they didn't have eyes, they didn't have arms, they didn't have a head, it was just like a flat cylinder". This testimony reveals how mobile and responsive agents appeal to children and how form plays a significant role in the interaction. Both boys were engaged by the expressiveness of Cozmo, and related it to human expressions. Through its eyes and movements, Cozmo was able to effectively communicate emotion, and so the children believed that Cozmo had feelings and intelligence. Many participants, who tried to engage in dialogue with the agents, were limited by the fact that the agents weren't able to ask clarifying questions. While the children were attracted to the voice and expressions of the agents at first, they lost interest when the agent could not engage with them. We recognize the potential for designing a voice interface that could engage in conversations with the children by referring to their previous questions, asking more clarifying questions and expressing various reactions to children inputs. In Cognimates we started to explore this direction by creating a platform feature (mission mode) where agents on the screen or embodied can react to the blocks that children are using in their code and give them instructions and feedback so they can learn how to program specific skills.

3.2.2 *Facilitating understanding*

While during the play-test the facilitators, parents, and peers helped the children rephrase or refine their questions, we wonder how some of this facilitation could be embedded in the design of the agent's mode of interaction. If the agent could let the children know why they cannot answer the question and differentiate between not understanding the question and not having access to a specific information, this would help the users decide how to change their question, either by rephrasing it or being more specific. Another issue we recognized was that sometimes the amount of information provided to the participants was overwhelming. The agent's answers could be scaffolded to provide information gradually. This would enable the children to decide how much they want to know about a specific topic and get more engaged by having a conversation with the agent.

We tried to address this guideline in our Cognimates platform design by not only allowing the agents to react and guide how children are coding them (mission mode) but also by showing young people how these agents perceive the world and what kind of information they can learn. We did this by providing children with access to the robot's camera on the platform stage and by showing them what are the things the agent is hearing or recording during the interaction.

3.3 HOW DO PARENTS INFLUENCE THE CHILDREN'S PERCEPTION OF SMART AGENTS?

The first study showed how much intelligence children attribute to computational objects, even when these devices fall short in conversations. This prompted us to further investigate how children perceive the intelligence of these devices in comparison with human or animal intelligence. We also wanted to explore what role do the parents play and how they influence their children's attitudes and mental models. To investigate this, we ran a pilot study where children watched videos of a small robot (Anki's Cozmo) and a real mouse solve a maze. We invited children to compare how they would solve the maze by tele-operating the same robot through it (see Fig. 11). We then asked children which agent was smarter in solving the maze and why. During the study, we also invited parents to participate in the experiment. Interestingly, we observed that in several cases, children and their parents expressed very similar choices and arguments even though they participated in the experiment separately.

In total, 30 pairs of children and their parents (some children were siblings) participated in the study. Three of the children had previously used the Cozmo robot. All participants were from the Greater Boston area, Massachusetts, U.S.A. Each participant watched videos of mice and robots solving a maze. Then the participants were invited to solve the maze by navigating a robot from a first-person perspective. We interviewed participants after each encounter to understand their model of the agent's mind, which agent they believed was smarter, and how they compared the intelligence of the agents to themselves.

First, we measured how similarly each child-parent pair answered the intelligence attribution questions after watching three different strategies of the mouse and robot solving the maze. The difference be-

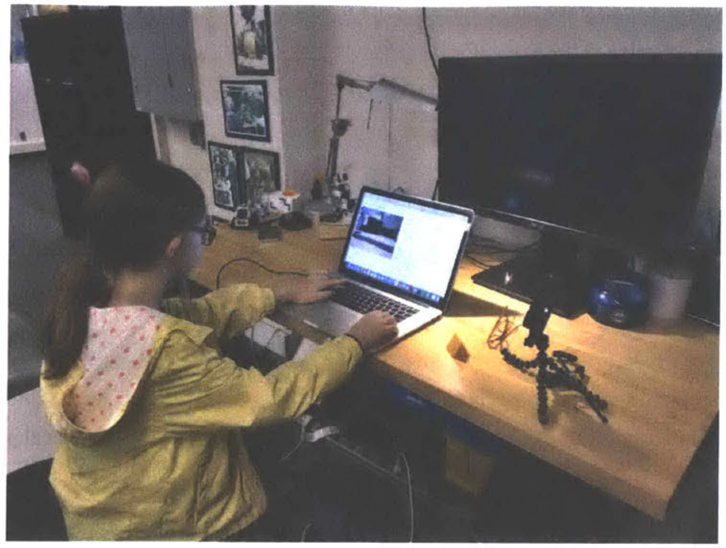


Figure 11: A 10 years old participant tele-operating the Cozmo robot

Figure 12: Study Setup: (a) Getting familiar with the maze; (b) Tele-operate the agent to solve the maze;(c) Take the intelligence attribution questionnaire and pre-test

tween two participants' ratings were normalized and weighted equally across six questions. Overall, participants including children and parents answered quite similarly to each other ($m=0.247$, $\sigma=0.11$). We analyzed how similarly each child-parent pair answered the questions compared to each other. Figure 13 presents agent intelligent rating distances between overall and younger and older child-parent pairs compared to distances between each participant and all other children and adults (non-child-parent pair). While we did not see significant difference between non-child-parent pairs, all-age child-parent pairs, and age 4-7 child-parent pairs, we saw significant similarity among older children (age 8-10) and their parents compared to the younger group ($p=0.024$) and non-child-parent group ($p=0.028$). This result suggests that by the age of eight, children form their perception of agent intelligence with heavy influence from their parents.

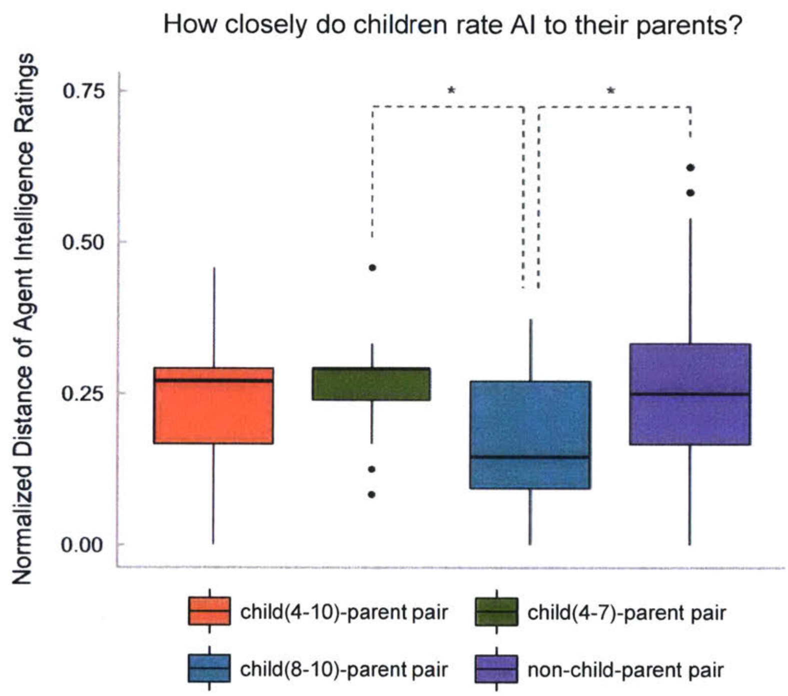


Figure 13: Normalized distance of agents intelligence ratings between child-parent pairs.

In this study we saw that although children and parents completed the study independently from one another they explained the agent behaviour and reasoning in very similar ways. In 21 of our 30 pairs, children and their parents chose the same agent as being more intelligent. Ten parent-child pairs even used very similar language when expressing their reasoning around how they perceived the agents' intelligence.

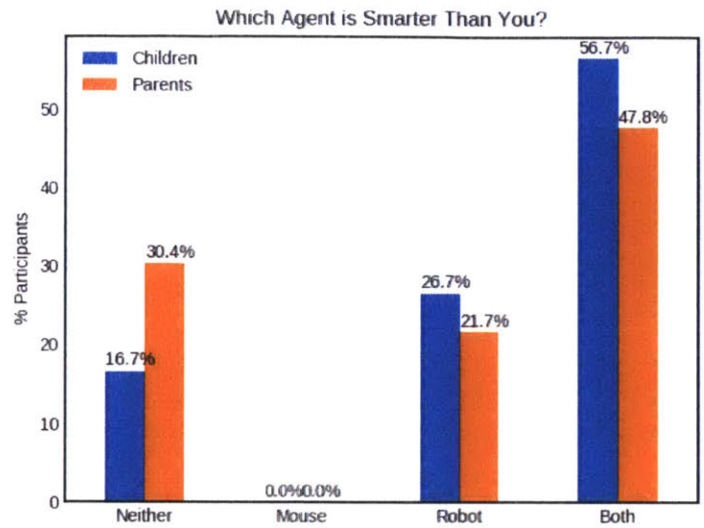


Figure 14: Children and parent responses to "Is the mouse smarter than you? Is the robot smarter than you?"

The only references made to agency were for the robot. All of the parents who made this argument believed that the robot was programmed. Children, on the other hand, either suggested that it was programmed, that someone was controlling it, or that robots are just naturally good at solving mazes. We saw that children relied on observable characteristics like performance, strategy, and sensory abilities instead of unobservable characteristics like cognition. This is in tune with prior work from Kiel et al. where children built their arguments first on observed characteristics [35].

Younger children (4-5 years old) were very creative with their arguments when their expectations contradicted their observations. For example, Liam (4 years old) said the mouse was very smart because he was very fast and he was very fast because he was very hungry. Then, after he watched the robot videos, he changed his mind and said the robot was even smarter and faster. When asked to clarify, he projected his understanding of the mouse onto the robot, "[The robot] was very fast because he was very hungry". Just like in this example, prior work showed that if children think of robots as analogous to an animal, they are more likely to apply a definition of intelligence that includes both cognitive and social/psychological characteristics ([7]).

We observed that many of the children's arguments about the agent's strategy became more complex after they got to solve the maze by controlling the robot. This lead us to wonder to what extent we can use tangible abstractions for reasoning (e.g. solving a maze) to help children gradually develop a higher level of understanding of computational objects. This inspired me to create extensions in Cognimates that would allow children to both tinker with the agent's behavior by programming it, and also enable them to modify it's environment by adding new objects it can sense and detect or making it communicate with other agents.

This study showed how closely children attribute agent intelligence to their parents align with prior studies showing parents' tendency to scaffold children's behavior while playing with robots or using other technologies such as interactive books [14, 23]. As our result suggested, by the age of eight, children already build their thoughts and perception of agent intelligence heavily influenced by their parents.

Based on our findings, I saw an opportunity to design a platform that would allow both children and parents to program and teach embodied intelligent agents and better understand the mind of the robot through making, experiencing and perspective taking.This would allow not only children, but also parents to have a more informed opinion about these technologies and not overestimate or underestimate them.

I believe, that in addition to building children's understanding of AI technologies they are growing up with, it is also important to prepare parents so that they can better assist and guide their families. The goal with the Cognimates platform is to make the programming of these agents accessible, collaborative and fun so that parents join their children in tinkering with these devices.

4 FROM CODING TO TEACHABLE MACHINES

" Our ideas about psychology are still developing so rapidly that it wouldn't make sense for us to select any current "theory of thinking" to teach. So instead, we'll propose a different approach: to provide our children with ideas they could use to invent their own theories about themselves!" —Marvin Minsky, OLPC Memo 5: Education and Psychology, 2009

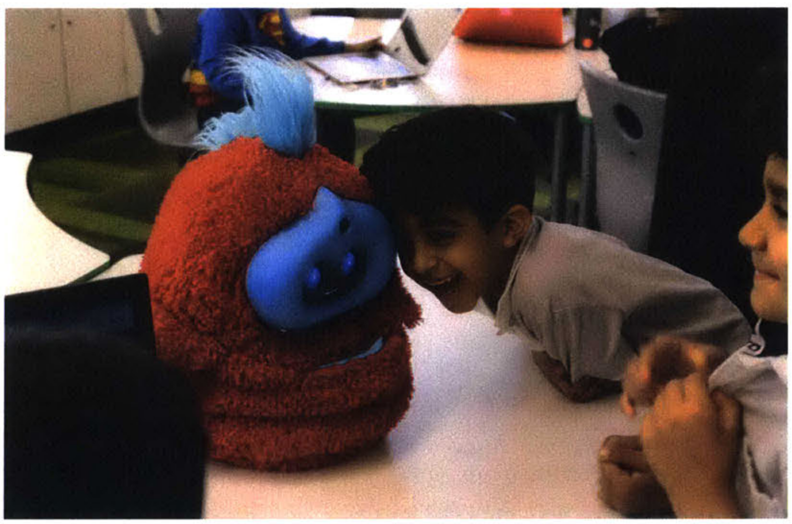


Figure 15: Student interacting with the Tega Robot developed in Personal Robots Group during Cognimates workshops at Riyadh international School

The design of computational objects for children is very much tied to the history of computing and technology. In the following chapter I will describe how the interaction of children with smart toys was studied before, how computing and coding were introduced to children, and describe existing initial efforts in teaching children about AI.

4.1 "PLAY THINGS THAT DO THINGS" AS OBJECTS TO THINK WITH

Previous research about children's interaction with computers explored the social role of intelligent toys in shaping and influencing the way young people learn. In her book "Second Self", Sherry Turkle describes these devices as relational artifacts that allow children to explore "matter, life, and mind"[64]. Similar to computers, current emerging autonomous technologies are inviting children to "think about thinking" [45]. Later on, Edith Ackermann also explored children's cybernetic intuitions when interacting with computational objects, which she described as "play things that do things" [2, 64].

This prior work has shown that children do not distinguish between causation and agency in the same ways most adults do. Instead, children, older than 5 years old, place these entities along an animate-inanimate spectrum due to their varying anthropomorphic characteristics [35, 58]. Their sense-making transitions from an initial observation of physical characteristics of a device to an understanding based on definitions. Their understanding based on observed characteristics, e.g., a robot, as an object "with wheels and sensors", is typically subjective, where the understanding based on definitions, e.g., the description of a robot as a programmable object, has a more universally applicable character [27, 51].

Figure 16: Example of smart toys used by Sherry Turkle in her initial study on children interacting with relational artifacts

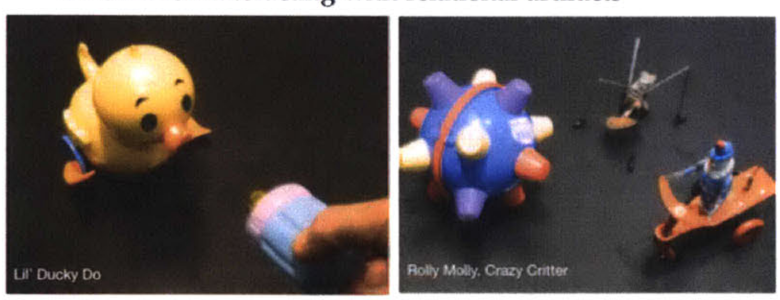


Figure 17: AniMates ("Play things that do things") used by Edith Ackerman in her study on children's cybernetic intuitions

In this context, animism is a powerful tool that young children bring to bear when trying to understand different aspects of the world like life, causality and consciousness. Overtime children learn to replace their innate theories with scientific definitions and explanations for many of the phenomena they observe. In doing so they draw a line between physical properties, used to understand things, and psychological properties, used to understand people and other living creatures [50].

Similar to the smart toys and games (Speak-and-Spell, Merlin Chess, Lil Ducky Doo etc, see 17) used by Turkle and Ackermann in their studies, the embodied intelligent agents of today like Alexa smart speaker, or Cozmo and Jibo social robots, represent marginal objects. They are placed between an object and a psychological entity, which incites children to form new theories about their nature, and wonder how the distinctions were drawn in the the first place. Today, these new devices are widely present in children's homes, and have many more complex features. This calls for new research to explore not only how children interact with these devices and perceive them, but also how they can develop a meaningful relationship with them over time. Together with my colleagues, we started to explore these new child-agent interactions and we observed that children do not always have the means to probe these computational objects through play [16].

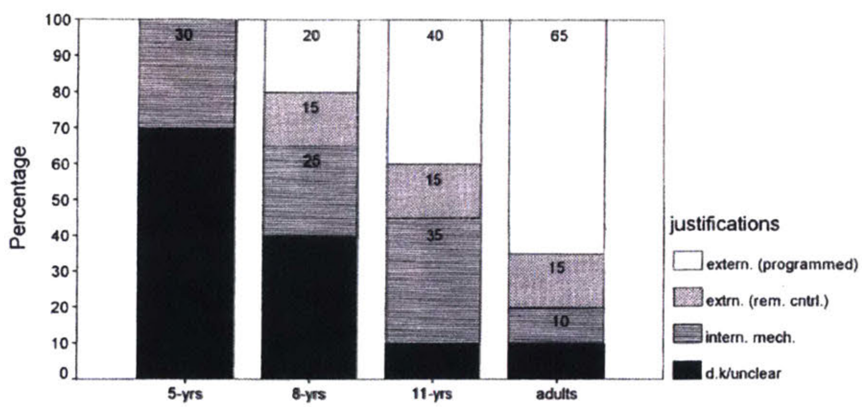


Figure 18: Children justification for computational objects behavior(from Duuren 1998 [19])

I was inspired by prior studies that recognize programability as a key concept in a domain-specific understanding of "intelligent" objects [19].Based on these findings, I decided to build a platform for AI education(Cognimates), that would allow children to program and teach the smart agents, and thus develop a better understanding of their inner workings. The underlying goal of this platform is to allow children to view the agents as "objects to think with" and not only "objects to be entertained with".

PROGRAMMING FOR KIDS

The history of developing programming platforms for children started in the early days of computers. In 1960s, after the invention of computer time-sharing and the development of the first high-level "conversational" programming language (JOSS), Wally Feurzeig was one of the pioneers who wanted to teach children how to program. The implementation of time sharing made it feasible and more affordable to use remote distributed terminals in schools and opened up the possibilities for interactive computer applications. Shortly after its invention in 1965, Wally decided to use TELCOMP (one of the new high-level interactive programming languages at the time) to teach children mathematics by coding. The project, which was supported by the US Office of Education, confirmed that using interactive computation with a high-level interpretive language would be highly motivating to students [69].

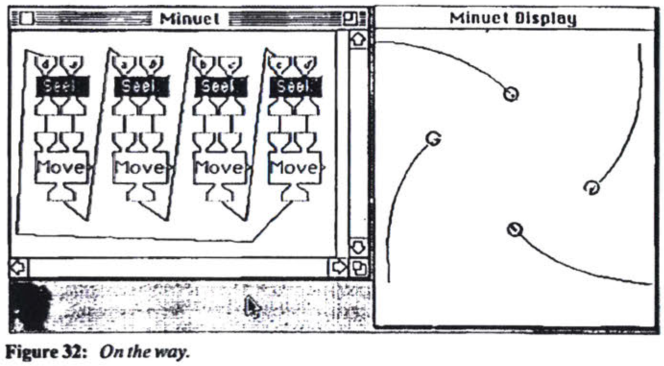


Figure 19: Function Machines interface developed by Wally Feurzeig and his colleagues at Bolt Beranek and Newman(BBN) laboratories in 1965 to teach coding to children

One year later, in 1967, Logo was conceived by Wally Feurzeig, Seymour Papert and Cynthia Solomon. Logo is regarded as the first programming language for children and is a multi-paradigm adaptation and dialect of Lisp, a functional programming language which was invented by John McCarthy. McCarthy also coined the term artificial intelligence and is regarded as one of the fathers of AI. The initial goal of Logo was to create a mathematical land, where children could play with numbers, words and sentences. Logo's breakthrough in terms of interface design was that it simplified the commands of LISP language, so children can easily read and manipulate them. The platform would also provide a window where children could see the output of their code.

In 1969, the first working Logo turtle robot was created. A display turtle preceded the physical floor turtle (see Fig. 20). Seymour Papert started to evangelize the importance of teaching children how to program as a new form of literacy, and started a new research lab dedicated to design technologies for education at MIT Media Lab. He advocated that by understanding how computers "think", children can reflect on their own thinking. He was visionary in exposing children to computational concepts in times when the computers were in their early beginnings and the access to this technology was restrictive and

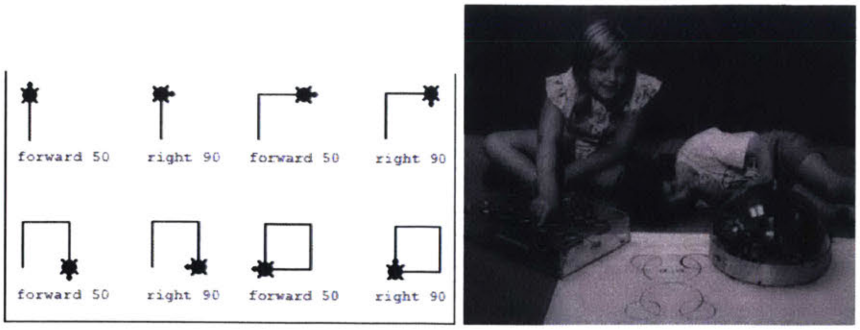


Figure 20: Examples of Logo Turtle commands and first Turtle robot programmed by children to draw in Logo, MIT Media Lab 1969

reserved mainly for research. One of his key ideas, which started the whole movement of constructionism in education, was that children learn best by doing. He created the LOGO language with the goal of enabling children to build and test their theories and ideas by tinkering, both in the digital and physical world. Later on, his work on Logo Turtle at MIT Media Lab inspired the development of LEGO Mindstorms, the robotic kit and software which is still being used today by children all over the world. The software interface for Lego Mindstorms, Legosheets, is the first visual programming language for children and it was created by Alexander Repenning at the University of Colorado in 1994, based on AgentSheets (see Fig.22).

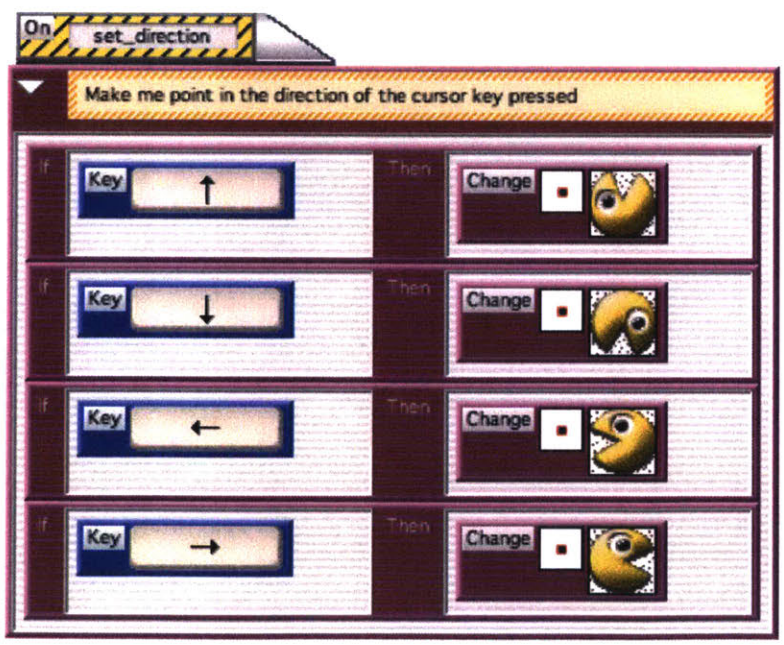


Figure 21: Examples Rules Scripts in AgentSheets programming platform for children, University of Colorado in 1994

A visual programming language(VPL) is a language that lets users create programs by manipulating elements graphically rather than by specifying them textually. Today there are hundreds of VPL versions and applications for teaching children how to program. The idea of manipulating visual blocks, which represent primitives of computational concepts, at the right level of abstraction is the main paradigm used when introducing children to coding and computational thinking.

Some of the popular platforms that are teaching children programming today are Scratch (MIT Media Lab), App Inventor (MIT Csail), Code.org and Lego Mindstorms.

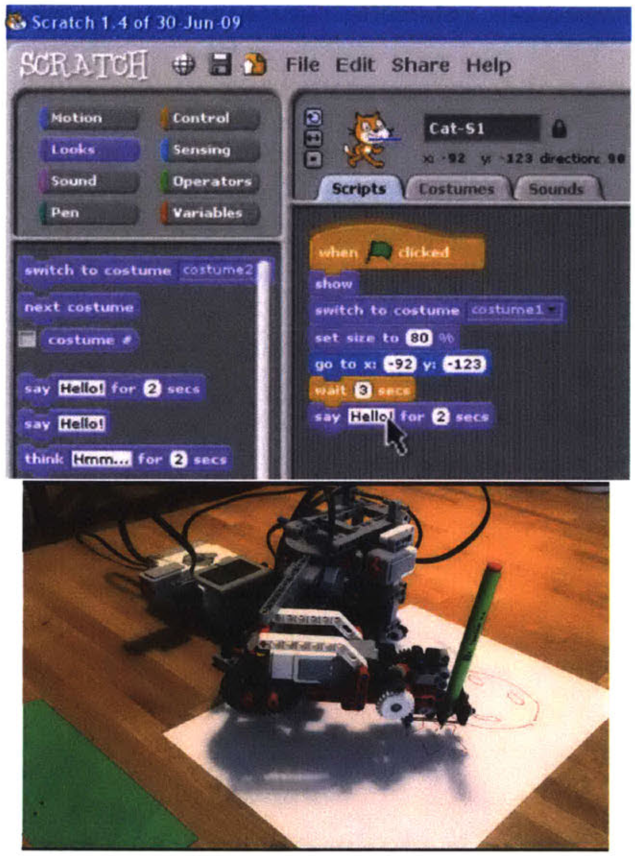


Figure 22: Examples of the first version of the Scratch platform launched in publicly in 2007 and Lego turtle programmed with Lego Mindstorms.

Scratch is the most widely used and known VPL for children and it was created 10 years ago, in the Lifelong Kindergarten Group at MIT Media Lab. The platform is based on Blockly, an open source library maintained by Google. It provides children with a wide vocabulary of blocks and characters. It also hosts a community page, where children can share, remix and comment on each other's projects. This platform is used all over the world and it is available in more than 50 languages. Scratch's intuitive and simple design, and its rich collection of characters, allowed children to build a variety of projects from animations, to games, simulations, art generators, etc. A different popular platform, which is also using Blockly library, is App inventor. This platform aims to enable children to develop their own mobile applications.

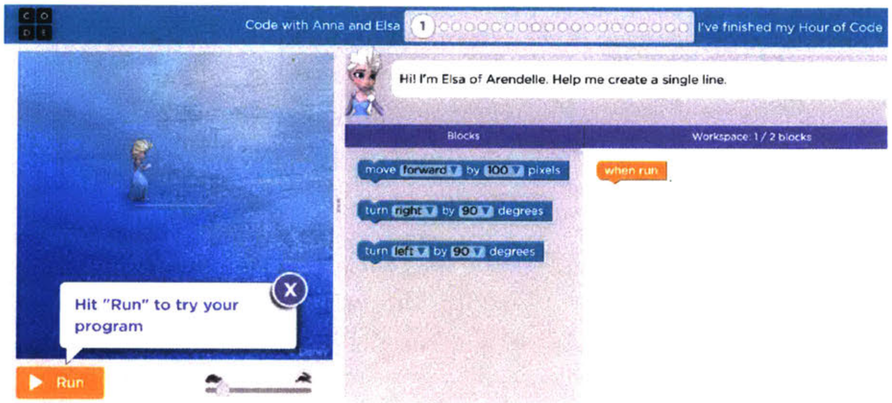


Figure 23: Examples of the coding activities for children on Code.org with Disney's "Frozen" movie characters

Both Scratch and App Inventor have been widely used in schools, teacher training and in world wide events like the "Hour of code", organized by Code.org. As more school districts adopt programming in their curriculum and STEAM education is becoming mainstream, we observe an "epistemological dilution" (as Papert defines it) from the original idea of getting children to create and think with code through play and free exploration. The way these platform and many other new VPL applications are currently used in mainstream global events and in schools subscribes much more to the instructionist model, rather than following the constructionist philosophy. Children are taught about variables, conditionals and loops concepts in prescribed ways. Very often the step-by-step coding activities are associated with popular Disney characters (see Fig. 23) or other Pop culture references to make them more attractive for youth. However, the design of these new coding platforms is leaving very little room for exploration, personal expression and deeper understanding. The parent's increased interest in STEAM education encourages also many hardware companies to launch coding platforms for their robotic kits, toys or microelectronic boards. While some of these companies put more thought into the design of their platforms, the overall trend is to oversimplify coding for children and make it "cool" and quick to consume rather than thought provoking.

Seymour Papert talked a lot about "hard fun", borrowing one of his student expression, when describing what learning by doing and by coding should be like for children. While the VPL platforms are meant to lower the barrier of entry and allow children to appropriate concepts of computational thinking in a fun and interactive way, they are not meant to be used as a prop for mass consumption of edutainment technologies and devices.

The evolution of coding tells a cautionary tale. Papert believed that computers will fundamentally change the way children learn fifty years ago when he democratized Logo. Today, we see how both public and private educational institutions, grapple in understanding his philosophy while trying to fit computer science education in their practice. I don't think children will want to learn how to code in order to get a good grade, or finish a class assignment or because it allows them to get a few more tokens on a mobile application. In order for children to truly engage and thrive in expressing their thoughts with code, the experience has to be challenging and generative enough.

Today, Artificial Intelligence is the "mainframe" that computers once were, and I strive to allow children to tinker, play and create with it, just like they did with LOGO in the early days. The goal is to focus on children and their learning and not on the technology, which is only an enabler and tool for young people to develop and express powerful ideas by doing.

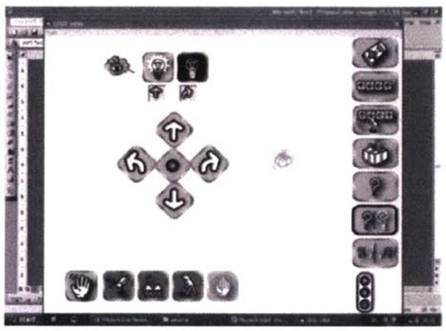
4.2 FROM CODING TO TEACHABLE MACHINES

The idea of a feedback loop is the core concept that is being introduced when children are transitioning from programming computers to programming and teaching embodied intelligent agents. Instead of just sending a series of commands to the agent, the youngsters also start to reflect on how the agent might represent the world, perceive the information that is being given to it and thus modify it's behaviour. Programming in this context calls for a scaffolded way for children to probe, and gradually understand the machine's emergent behavior.

Mioduser et al. explored how children could understand emergent machines by gradually modifying their environment, [41]. They discovered that children are capable of developing an emergent schema when they can physically test and debug their assumptions, by modifying the environment where robots perform a task. They also showed that the number of rules and new behaviours should be gradually introduced in the coding activity (see Fig.24).

The democratization of current AI technologies allows children to communicate with machines not only via code but also via natural language and computer vision technologies. This makes it easier for a child to control and even "program" an agent via voice, but it makes it harder for a child to debug when the machine doesn't behave the way he expects. A core challenge becomes then to make the agent reasoning more transparent, and allow the child to understand how the machine perceives and models the world [26].

In this context, it is worth interrogating how a future interface that allows young people to program and teach smart agents should look like. In the previous section we saw how the initial programming lan-



(a) The behavior-construction interface

(b) The Lego-made robot

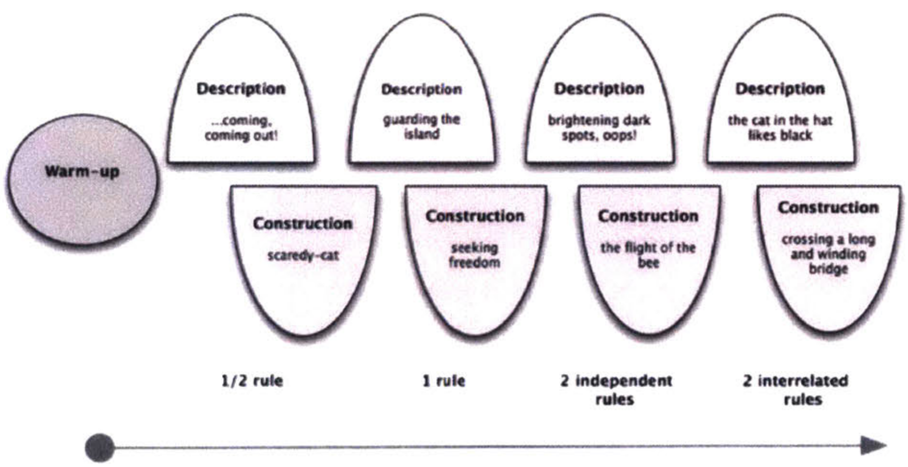


Figure 24: Example of robotic platform and scripting rules used by Mioduser et al. in order to observe how children develop an emergent schema [41]

guages for children would include both rule-systems, agent behavior simulations, logical and math primitives while the more recent versions of VPL focus mainly on basic computational primitives.

while the early days of rule-based coding interfaces for children (AgentSheets, KidSim, Cocoa, Creator) serve as an inspiration, we see an opportunity to design new multi-modal programming platforms for children. For this we created Cognimates, as an interface for teachable machines, that includes a VPL grammar for scripting voice commands, integrating and creating custom vision and text classifiers. Our platform also has a staging area, where the child can see what the agent sees, hears or senses (light, motion, temperature). In using our platform, the children are not only programming the smart agents with simple commands, but they are also teaching the computational objects how to recognize different objects and express different behaviors.

Figure 25: Example of children teaching robots how to play Angry Birds, study conducted by Park et al. 2004 [46]

Chou et al [15] previously explored constructionist scenarios, where students can teach the learning companion, and thus "learn by teaching". This approach aims to encourage the student to provide the learning companion with knowledge and examples, to observe how the learning companion solves the problems, and to explain why the solution of the learning companion is correct or incorrect. The same approach has been researched further by a number of researchers [66, 67]. Prior studies from our research group also show, that children not only learn from robots things like curiosity, growth mindset, and different language skills, but they are also willing to teach the robots how to play games, solve puzzles and tell stories [**gelsominiaattentiv**, 11, 25, 46, 48]. Based on these findings, I see an opportunity to use the smart toys and agents that are becoming embedded in children's homes as more than entertainment devices. I foresee how these devices could become learning companions, that children can teach and program with the Cognimates platform.

4.3 CURRENT EFFORTS FOR AI EDUCATION

While artificial intelligence technologies are still mainly developed and used in academic research and large scale commercial applications, currently there are a few initiatives that try to democratize access to AI for a wider audience.

Some of the first platforms that demonstrate different machine learning algorithms were created by Google and are accessible in this collection : `https://experiments.withgoogle.com/collection/ai`. We tested these applications with children, during pilot workshops, and found that the most adapted demos for children are the Teachable Machine, Quick Draw and Emoji Scavenger Hunt. The Teachable Machine allows students to teach the computer three things at a time by taking pictures of different gestures or objects. When different objects are identified, the output on the computer changes and children can see different animations and hear different sounds. The Quick Draw platform allows children to make drawings while trying to guess what they are sketching. The Emoji Scavenger Hunt is more like a game where children are given emojis for different objects. The game users have a limited time to find these objects (books, plugs, phones), and make the computer recognize them. The goal of the game is to find as many objects as possible. While children enjoyed very much trying these different demos, after they played with them once they get bored and want to switch to a different activity. These demos are not generative enough and children cannot use their different components to build and create their own projects. In our work with Cognimates, we integrate some of the concepts demonstrated in these platforms (like visual recognition), but also provide primitives(blocks) that children can use to customize and create a variety of projects, while gaining a deeper understanding of the underlying AI technologies.

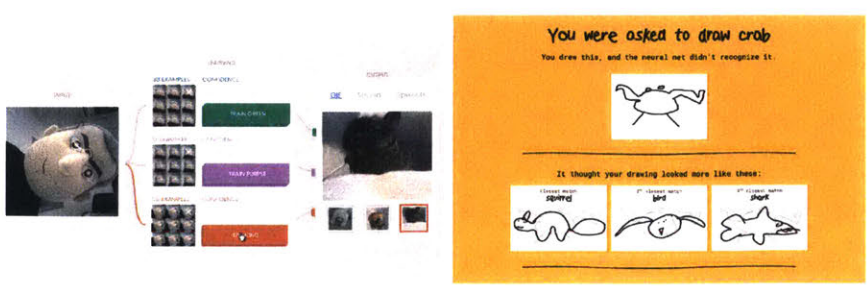
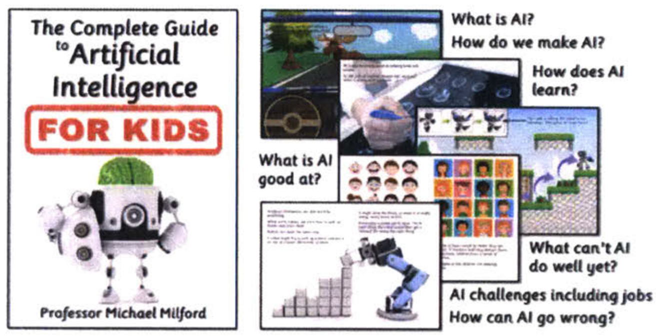


Figure 26: Google platforms

More specifically focused on AI education, I came across an AI for kids guide created by a robotics teacher, who is also a parent. The guide is made for younger children (3.5 - 6 years old), and contains a collection of drawings and stories,which are meant to explain in a very intuitive way how robots and machine learning works (`http://bit.ly/ai_kids_guide`). In our group, my colleague Randi Williams, has also created a coding platform for pre-k children, allowing them to program custom Lego robots with blocks that only have images. Her Popbots platform has been used by children to create simple rule-based programs for sorting foods, playing games or making music (`https://www.media.mit.edu/projects/pop-kit`).



The Complete Guide to Artificial Intelligence for Kids

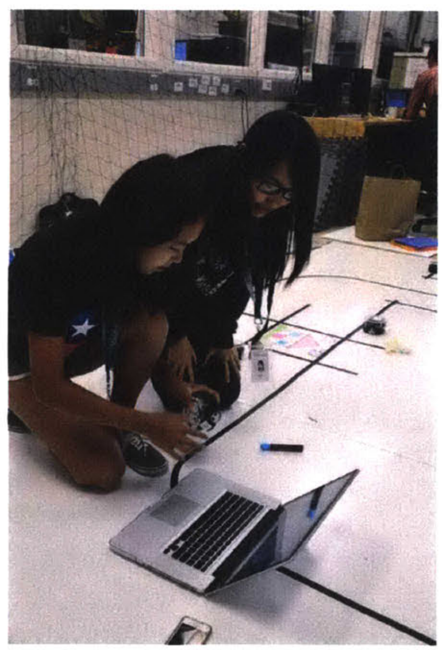


Figure 27: Examples of AI for kids guide recently launched on Kickstarter, and AI4All summer camps for young adults

While these initiatives are targeting very young children, for older children AIEd camps and after school workshops are starting to rise. The AI4All initiative, started by Dr.Fei-Fei Li and supported by Google, provides summer camps for teenagers and young adults. Their curriculum is not public yet and they are mainly using more advanced tools like tensor flow and python language in their lessons. Id tech and Digital Media Academy also offer computer science summer camps on college campuses across the country, geared towards older middle school and high school students. They recently integrated a machine learning and deep neural networks activity, where students can learn how to create a neural network, train models to learn without being directly coded to do so. These camps encourage older participants to dive into Tensor Flow, and get experience coding with languages like Python.

While we see there is an increasing interest from both parents and children to learn more about these technologies, existing initiatives are targeting mainly older children. They use complex off the shelf AI libraries like Tensorflow and Pytorch, and require children to already have advanced programming skills. My goal with Cognimates is to democratize access to these technologies for children 7 to 14 years old, and provide them with tools and learning activities that are adapted for their age. In this research project is also aim to inform the design of intelligent agents and AI technologies as “glass boxes“ (in contrast to "black boxes") where the essential elements of the agents‘ reasoning can be understood and modified by learners. As Erickson points out , the user needs understanding of what happened and why [20] and this is what I hope to achieve with the Cognimates platform. Prepare a generation that is growing up with these technologies to not only read but also write AI and have fun along the way.

5 COGNIMATES: A PLATFORM FOR AI EDUCATION

> "At first I didn't really know computers got taught. I thought computers, once they were invented, knew stuff", Mia, 7 years old

Figure 28: Children programming with Cognimates at Portfolio School in New York

Cognimates (`http://cognimates.me`) is a platform we designed where children (between the ages of 7 and 12) could program and customize embodied intelligent devices, such as Amazon's smart speaker and the social robot Jibo. Cognimates is based on the Scratch 3.0 open source block language, created by the Lifelong Kindergarten Group at the MIT Media Lab. For Cognimates, we created a collection of dedicated extensions for home tinkering with AI devices and services (Jibo, Alexa, Smart Lights and Plugs, Color Tracking, Image Recognition, etc). See Table. 3. Programming is done by connecting visual blocks together from each Cognimates extension.

5.1 BUILDING ON EXISTING CODING PLATFORMS FOR CHILDREN

With S.T.E.A.M education going mainstream, coding has become a literacy for children. It is being integrated into school curriculum and teacher training programs around the world. Most of the coding platforms for children use a visual programming language based on blockly, an open source library maintained by Google, that makes it easy to add block-based visual programming to an app. It is designed to be flexible and supports a large set of features for different applications. It has been used for programming characters on a screen; creating story scripts, and controlling robots.

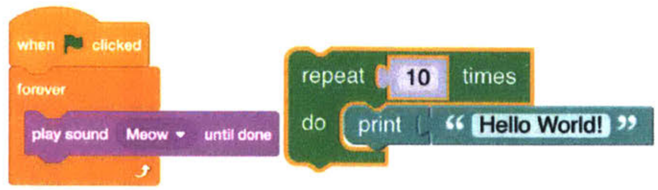


Figure 29: Example of Scratch and Blockly Vertical Grammar

A Visual Programming Language (VPL) is a programming language that allows a user to create programs primarily through graphical manipulation. Some common interaction models in VPLs are:

- Dragging blocks around a screen (e.g. Scratch Fig.29)
- Using flow diagrams, state diagrams, and other component wiring (e.g. Pure Data)
- Using icons or non-text representation (e.g. Cozmo Codelab Fig.55)

Many VPLs still use text or combine text with visual representations. Every VPL has a grammar and a vocabulary. Together, they define the set of concepts that can be easily expressed with the language. The grammar is the visual metaphor used by the language: blocks, wires, etc. The vocabulary is the set of icons, blocks, or other components that allow you to express ideas. The Blockly core library is written in JavaScript and can be used as part of any website or can be embedded in a WebView. Native Android and iOS versions of Blockly are also available. They provide a subset of features for building high performance mobile apps. As a library, Blockly is neither a full language nor an app that is ready for end users. Rather, Blockly provides a grammar for block programming [49].

The Scratch platform (`http://scratch.mit.edu`) is the largest coding platform for kids worldwide. It was created at MIT ten years ago. It also use the Blockly grammar and engine for the latest version of the platform (Scratch 3.0), and it can be used on both on desktop and mobile devices.

Because children are already very familiar with how Scratch VPL looks and works, I decided to use the same blocks grammar for the Cognimates platform. Before building a new platform, I also investigated shared projects by the Scratch community to see if children are already coding and interested in AI projects. I found more than 10,000

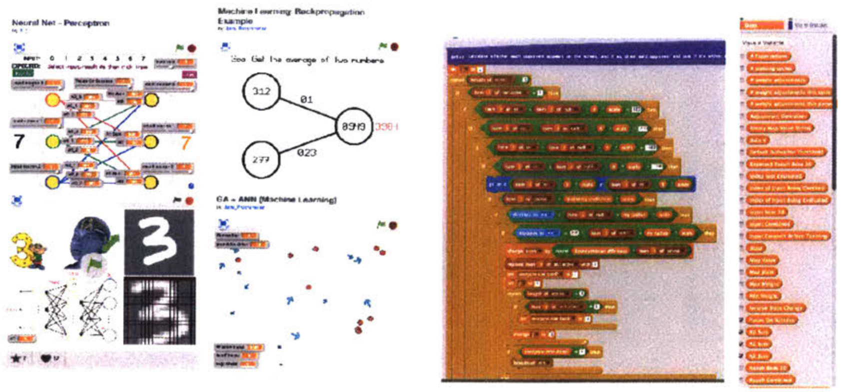


Figure 30: AI projects kids built on Scratch

projects tagged either with the terms "artificial intelligence","AI" or "neural networks". After obtaining IRB approval and support from the Scratch team in Lifelong Kindergarten Group at MIT Medialab, I started to analyze all these projects.

The main categories for the created projects were: AI games, chatbots, visual generators and simulations. Some of the most impressive projects recreated complex machine learning algorithms: OCR for handwritten number recognition, Neural Networks for color matching, Back-Propagation, GANs for simulations. However, the code behind these projects was extremely complex and almost unreadable (see Fig. 30). The majority of these projects were never remixed (modified by other users). They were also created mostly by users older than 16 (see Fig.31).

This encouraged me to design a new series of extensions and blocks which would encapsulate AI primitives and functionality at the right level of abstraction. Some of the math and calculations are done "behind the scenes" – children can work with AI concepts at a logic level (e.g., "image detected", "confidence level", "sentiment of text" blocks rather than long lists of cloud variables). The goal in designing such a platform was to lower the barrier of entry. I wanted to still allow older children to learn about these concepts by doing – and also to encourage more collaboration, remixing and tinkering.

5.2 THE PATH TO COGNIMATES

Besides the machine learning algorithms that children were playing with on Scratch, I also came across an open source 3D printable robot, Poppy Ergo Jr. This was developed by the Flowers Group at Inria Bordeaux in France (`http://www.poppy-project.org`). I was very inspired by the fact that this robot had encoded actuators that could record and replay a movement. I immediately start imagining how children could teach such a robot by demonstration (e.g., tech it how

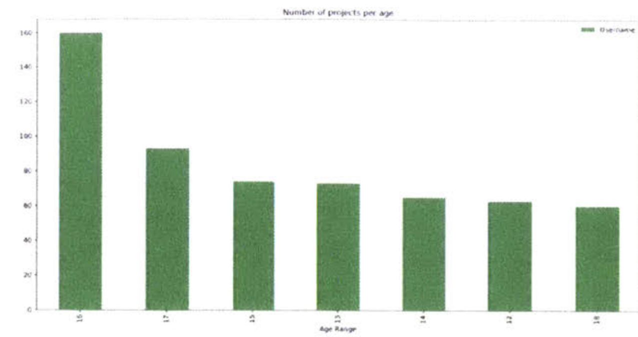


Figure 31: Ages distribution of Scratch users building AI projects

to draw or move like a dog). The Poppy project already had a VPL Snap platform for the robot, but I wanted to make the coding more accessible and modular. So, I decided to build a Scratch Extension for this robot. This was the first Scratch extension I built in the beginning of 2017, together with my undergrad intern, Eesh Likhith.

A Scratch extension is a module that provides a limited number of blocks to control a specific web application, service (e.g., Spotify or Twitter), or a hardware device (e.g., a robot, IoT device). The module can be loaded into a dedicated Scratch platform (http://www.scratchx.org) where it can be combined in projects with all the other existing extensions created by others in the community. The main purpose of Scratch extensions is to extend coding to the real world and provide children with an accessible way to program by combining various computational objects and web services. Scratch extensions are written in the javascript language and are composed mainly of two parts. The first part includes the blocks definitions where the type of blocks (e.g., command, reporter, etc) and their language are defined). The second part defines the functions that will make calls to web APIs or custom servers when a block is clicked.

After creating my first Poppy Scratch extension (which would allow children to program the Ergo Jr. robot to perform specific actions and gestures) I thought it would be great if they could combine that with computer vision. The learning scenario I had in mind was that children would show an object to the robot (which also had a webcam), and the robot would try to draw it based on the objects they taught the robot how to draw (see Fig. **??**).

For prototyping this interaction together with Eesh, we started to work on a new Scratch extension for computer vision that used the public Clarifai API for image recognition. After we build two extensions and tested them with children, we realized that from an interaction perspective, it was hard for children to tell what the robot was actually seeing. It didn't have a screen, and therefore hard to debug the way they were framing and holding the objects. Based

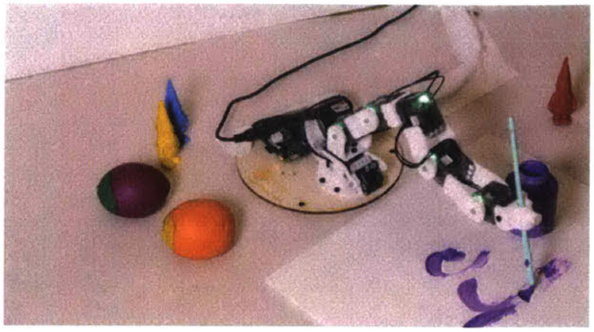


Figure 32: Poppy Ergo Jr Robot Programmed to draw by demonstration

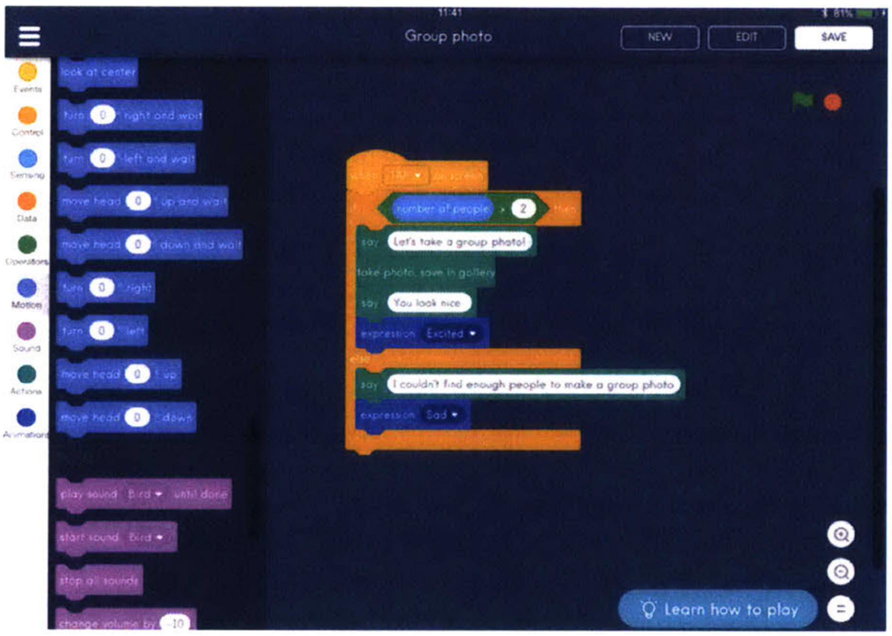


Figure 33: Example Jibo BeAMaker coding app

on this experience, we decided to simplify our implementation and add a series of QR codes that the robot could recognize. Kids could print them on paper and the robot could associate them with objects. This worked much better, and children really enjoyed holding images that would make the robot act happy, sad or move like a dog. A full video of the various interactions can be found here: `https://vimeo.com/218055021`. Both the Poppy Robot and Clarifai extensions were documented and published on the Scratchx.org gallery.

After building and testing these first extensions, I became more interested in AI education. I started to collaborate with Randi Williams from Personal Robots Group. She was interested in designing and building an AI coding platform for pre-school age children, whereas I wanted to design tools and resources for older children (7-12 years old).

Coding Platform	Desktop version	Mobile version	Modular (extensions)	Cognitive services	AI training
Scratch	*	*	*		
Cozmo Codelab		*		*	
BeAMaker		*		*	
Blockly	*	*			
Mindstorms		*	*		
ML 4 kids	*				*
Cognimates	*	*	*	*	*

Table 1: Comparison of existing coding platforms and Cognimates

We decided to join forces and run a first study to explore how children perceive and interact with smart agents and toys [16]. As a result of this collaboration, I decided to also transfer to Personal Robots Group and focus my master research on AI education. Based on the findings of our first study, Randi went on to create the Popbots Preschool Programming Platform (`https://www.media.mit.edu/projects/pop-kit`). I began to work on a dedicated VPL platform for the Jibo robot in collaboration with Diego Munoz, from NTT Data (a Media Lab member company). This app later ended up being launched publicly as the BeAMaker app (`http://beamaker.cloqq.com/`).

The VPL app for the Jibo robot (or "Scratch for Jibo" as I used to call it) was very well received in user studies both by children and by parents. However, if I wanted to test it and deploy it in schools at scale– the issue of limited access to the robot become a barrier.

I decided to return to my ideas from the first prototypes with Scratch extensions and build the Cognimates platform. This would include extensions for robotic and smart agents like Jibo, Cozmo or Alexa. But would also allow students who had no access to hardware to program with cognitive services (e.g., Clarifai, Sentiment Analysis, Color detection) or to build and train their own classifiers for images and text (for instance, using IBM Watson Extensions for Vision and Text).

In the design of the Cognimates platform, I tried to combine what I considered to be the most important features of previous coding apps (i.e., intuitive blocks, access on mobile devices, connection to the physical world, and hardware devices). I also added modular extensions for cognitive services in addition to intuitive AI training capabilities. These were specifically designed for education (see Table.1).

5.3 CHILDREN AS DESIGN PARTNERS

The most important contributors to the design of the Cognimates platform are the children who were involved in all testing and development phases of the platform. I was initially worried to test bare prototypes with young students and their families. So, for the first tests I invited a group of families that I knew fairly well and with whom I had worked with on different projects. To my surprise, the children were actually excited to help debug and contribute to an ongoing research project! They would spend a significant amount of time searching for glitches. They were very proud when they were able to figure out when the robot would not do as it was supposed to. The key was to manage their expectations at the beginning. I told them that the platform is still "in construction" and that they are helping us make it better. This helped to avoid having them get frustrated by bugs and actually engage the children in trying to fix those bugs. Later on, during the study, the students would describe to us how they imagine future AI and robots to be like. The shared how they would like the Codelab characters (sprites) to look, and how to improve the training page (Tech AI). We made new designs and iterated with them until we go designs that children liked (see Fig. 49).

In order to leverage children's strengths as design partners, a relationship of trust has to be established. During the different workshops, I made a point to show them how I changed the language of a block, or added a new feature, based on their suggestions. This made them truly engaged with the activities. It made them feel that their voice matters.

As Allison Druin points out: "children have so few experiences in their lives where they can contribute their opinions and see that they are taken seriously by adults". She argues that such experiences can build confidence in children both academically and socially and produce "design-centered learning" [18]. Experiencing the power of this kind of learning, and the joy of co-designing and building for and with children, was one of my favorite parts of this project. I consider it to be a critical process for the design of all new and unexplored technologies that support children's development and learning.

5.4 PLATFORM OVERVIEW

The Cognimates platform comes with the following components:

- **Codelab**: this is where children program their projects. It has 5 main components (see also Fig.34):
  - 1. navigation bar: for saving and loading projects

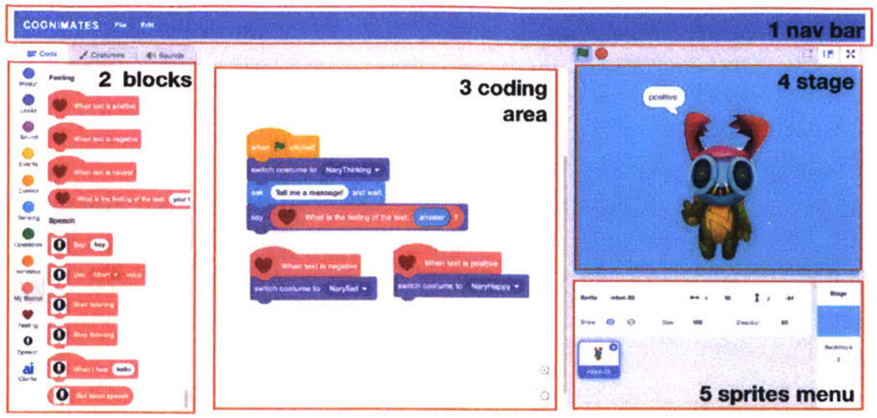


Figure 34: Cognimates Codelab high-level components

- 2. blocks library: where all core blocks from the Scratch Grammar are available and new Cognimates extension blocks can be added
- 3. coding area: where children can drag and drop blocks and combine them together to create a program
- 4. stage area: where users can see the output of their program
- 5. sprites menu: adding and modifying sprites

- **Extensions gallery**: the platform provides 18 AI extensions. All of them can be loaded and used in the Codelab. A full summary of the extensions and their capabilities is presented in Table.3 and Table **??**

- **Teach AI**: this is the page where children can train their own classifiers by providing examples of images and text. The page is using IBM Watson SDK and API for custom classifiers (see Fig.**??**).

- **Starter Projects**: in order to help children and teachers get started, we created a gallery of 20 starter projects that demonstrate how different extensions work, or how children could add new AI features.

- **Learning Guides**: in order to support teachers and parents to use this platform in the classroom or at home, we also created a series of step-by-step learning guides (all guides are included in the Appendix).

- **Missions**: some of the extensions (Cognimate, Jibo, Cozmo) also have a mission mode. This allows either the computer or the robot being programmed to react and give feedback to the child based on the blocks he or she is using. The goal of the missions is to enable the agents (or the computer) to act as a learning companion while guiding the children to learn how to program specific projects.

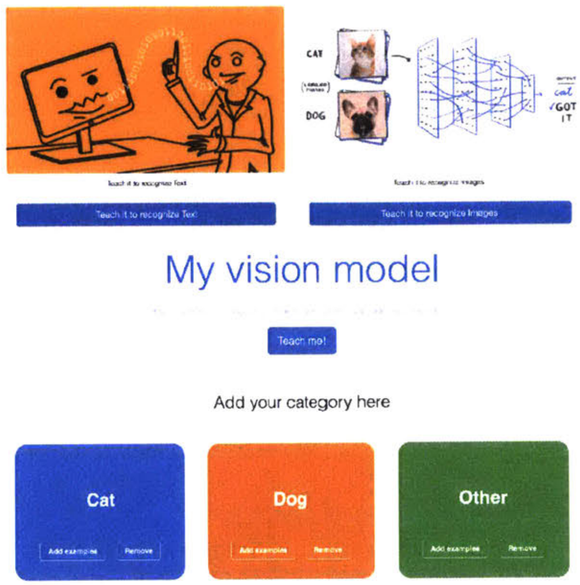


Figure 35: Cognimates Teach AI high-level components

5.4.1 *Platform architecture*

In the following section I will describe the technical architecture of the three main technical components of Cognimates: the Codelab, the TeachAI page and the Alexa custom skill and extension. All the code developed for this platform has been made open-source. The Codelab builds on Scratch 3.0 open source code published by Lifelong Kindergarten Group at the MIT Media Lab, the Teach AI is using the IBM Watson API, and the Alexa skill builds on the official Amazon SDK and webservices.

Cognimates Codelab

Behind the scenes of the Codelab, there 4 main components:

```
\item The platform's GUI (represented in Fig.\ref{fig_cog_interface} by
    the navbar, coding area and sprites menu) is a React-based front end
    application (\url{https://github.com/mitmedialab/cognimates-gui}).
\item The Virtual Machine (VM)(represented in Fig.\ref{fig_cog_interface
    } by the blocks section) - manages state and does business logic. It
    sends the state to the GUI
\item Cognimates Blocks - branched from Blockly and Scratch Blocks. This
    repository handles both the UI and logic for the portions of the
    editor that blocks appear in. Talks to the GUI, which often pipes
    things through to the VM (\url{https://github.com/mitmedialab/
    cognimates-blocks-}).
```

```
\item  Renderer (represented in Fig.\ref{fig cog interface} by the stage
    section) - WebGL-based handler of what appears in the stage area.
    The GUI tells it what to do.
```

Teach AI page

The Cognimates Teach AI page classification system consists of four components:

- a controller: responsible for linking classifiers to their respective users and communicating with the IBM Watson API.
- a page for creating new classifiers
- a page for deleting new classifiers
- a page for updating new classifiers

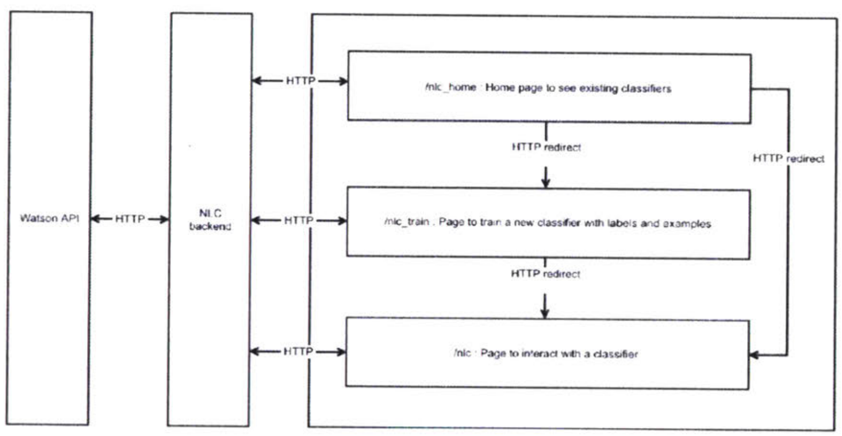


Figure 36: Cognimates Teach AI Platform architecture

The Nlc home page is responsible for listing all the classifiers that belong to a user. The view makes a GET request to "/nlc/classifiers" with the access token in the header to get a list of classifiers. It also allows a user to specify a new project name and initiate the process of training a new classifier. It does this by setting the user specified classifier name in the localStorage using the 'temp_classifierName' key and then redirecting to the /nlc_train page.

The Nlc train page facilitates the process of training a classifier by creating labels and associating examples to different labels. When the page loads, it fetches the 'temp_classifierName' item in localStorage. Once the labels and examples are specified and the user clicks train, a POST request with the classifier name and training data is sent to /nlc/classifier. Upon successful classifier creation, the classifier_id from the response is stored in the localStorage with the key 'selectedClassifier' and the browser is then redirected to the Nlc homepage.

The Nlc homepage facilitates the interaction with a classifier. It refers to the 'selectedClassifier' key in localStorage on load and fetches the classifier information by making a GET request to '/nlc/classifier' with the classifier id. If the user intends to delete the classifier, a DELETE request is made to '/nlc/classifier' with the same id. To make a prediction, a GET request is made to '/nlc/classify' with the phrase to be classified and a classifier id.

Cognimates Alexa Skill

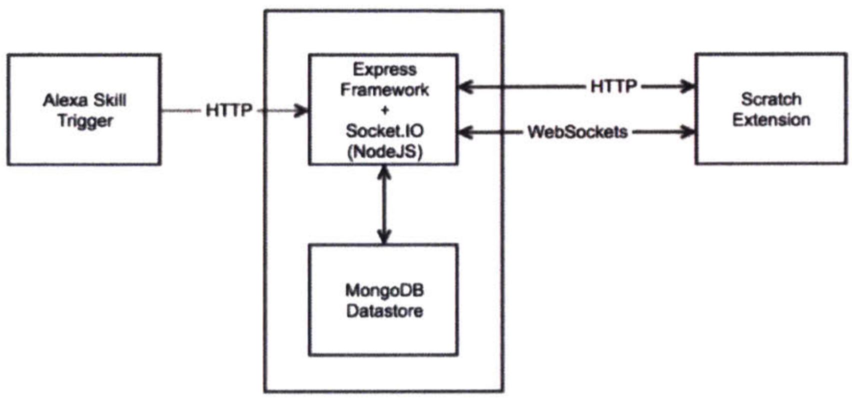


Figure 37: Cognimates Alexa skill architecture

For the Alexa Cognimates Skill we used a NodeJS backend which hosts our REST APIs. We are using Express Framework to write these APIs easily. To store data, we are using MongoDB, a NoSQL database. We access mongoDB from NodeJS server using mongoose module. We also have a WebSocket server running on the same NodeJS server. We use socket.io module for this purpose. Our websocket server is used to communicate with our Cognimates extension client (see 39).

When a user logs in through Cognimates, the user is given a 5-digit access code. The user can use this access code to login through Alexa via voice. The Cognimates client connects to the websocket server and sends a registration request containing the access code. The Websocket server identifies the user using the access code and saves the current socket ID of the user.

When the user asks the answer to a question where he programmed the answer on the Cognimates extensions, The Alexa skill makes a request to the express server with the authentication token of the user that the skill has received after logging in using the access code. This authentication is unique to every user and is used for further requests to save or get details regarding the user. When the user asks Cognimates Alexa skill to run a block set on the Cognimates extension, the request is sent to the express REST API with the users authen-

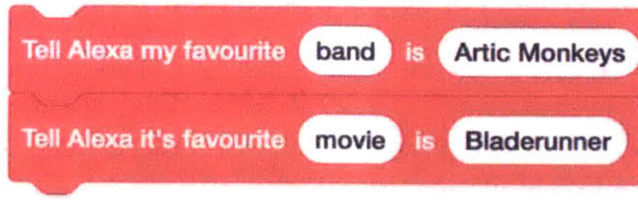


Figure 38: Examples of things children can teach Alexa via the Cognimates Skill and Extension

tication token. The NodeJS server identifies the user using this authentication token, gets the current socket ID of the user, and sends the run block set command to the Cognimates client using the active socket connection. The Cognimates Alexa skill has been published on Amazon's official list of Alexa skills for children and anyone who has an Alexa device can use it for free. A video demonstrating all the skill and extensions capabilities is available here: `http://bit.ly/cogni_alexaskill_demo`.

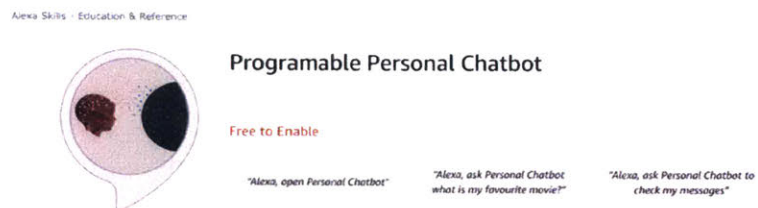


Figure 39: Cognimates skill for Alexa published on official Amazon Education skills gallery, `http://bit.ly/cogni_alexaskill`

5.5 EXTENSIONS DESCRIPTION

This section provides a summary of all extensions developed for the Cognimates platform. These extensions were built using the open source code from Scratch 3.0. Blocks provided by Lifelong Kindergarten Group at the MIT Media Lab are available here: llk.github.io/scratch-gui.

The language, shape, and type of blocks used across the different extensions have been designed to be consistent and easy to understand based on children's direct and indirect feedback (see Fig.41).

5.6 COGNIMATES PROJECT EXAMPLES

In this section, I provide a series of starter project examples to illustrate the variety of projects built by children, how the same extensions

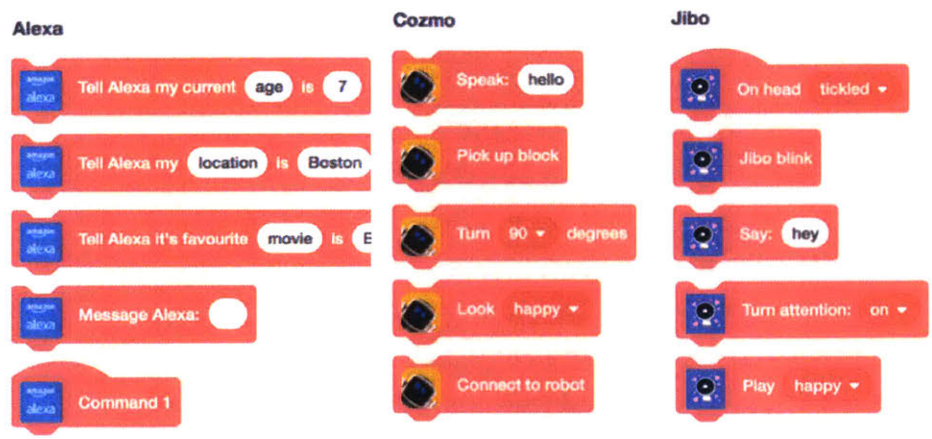


Figure 40: Example of Extensions Blocks for Smart Agents: Alexa, Cozmo and Jibo

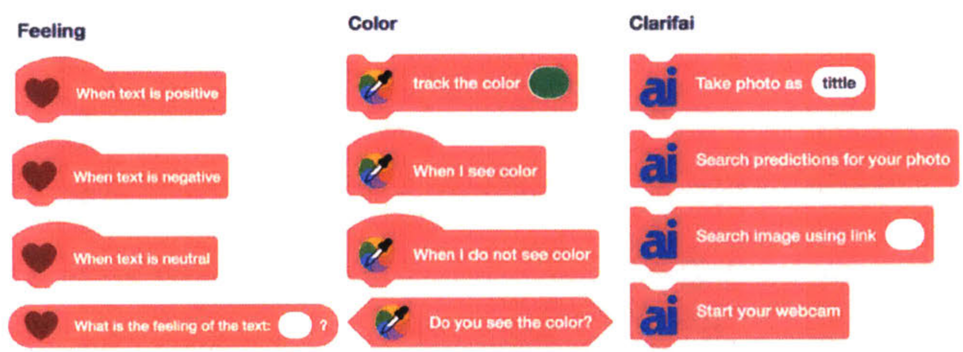


Figure 41: Example of Extensions Blocks for Cognitive Services: Feeling detection, Color tracking, Image Classification

Extension	Functionality	Implementation
Cognimate (learning companion)	This extension will guide users through different tutorials (missions) to teach them specific programming concepts.	Users can choose among 20 voices (all English) Using WebSpeechAPI (MIT Licence).
Jibo (robot extension)	Program Jibo robot to move, speak, perform specific animations, take pictures, detect motion or touch.	Uses Jibo SDK and remote skill which enables secure connection to API.
Ergo (robot extension)	Program Ergo robot to move, change LED colors, it can also record motions and play them back (learning by demonstration).	Using Inria Flowers open source API for Ergo Robot.
Cozmo (robot extension)	Program Cozmo robot, it can access it's camera so children can see what the robot is seeing and teach it to recognize different objects (supervised learning)	Uses Anki's Cozmo SDK. Connects to the robot via a paired phone running the Cozmo App in SDK mode
Clarifai (cognitive service)	This extension uses a webcam to take pictures get predictions about their content.	Uses Clarifai SDK and API for image classification.
Feelings (cognitive service)	Detect sentiment of text as positive, neutral or negative (it parses both words and longer phrases).	Uses NPM Sentiment package based on AFFIN public library.
Color (cognitive service)	Detect specific selected colors (color sensing).	Uses Tracking.js public libraty
Alexa (smart assistant)	Teach Alexa specific things, enable it to trigger other actions in the program via voice, leave messages.	Alexa Skill Trigger (Personal Chatbot) Express server connecting to extension. Mongodb Database
Smart Light (IoT)	Program Hue Lights to change color.	Using Huepi Javascript public library.
Smart Plug (IoT)	Program Wemo plug to turn on and off and control everything connected to it (lamp, disco ball, bubble machine).	Using Wemo Client Javascript public library.
Speech (NLP)	Used for natural language processing (text to speech and speech to text).	Using Google Speech Web API.
Video (Sensing)	Used to get access to different external webcam and to detect video motion.	Using Google Chrome Web API

Table 2: Cognimates extensions part 1

Extension	Functionality	Implementation
Twitter (Web)	Get access to tweets from specific user or hashtag.	Using Twitter SDK and public API
Microbit (Hardware)	Program the BBC's microbit board to detect motion, touch, change LED.	Customized Microbit firmware, BLE web connection.
MUSE Headband (Hardware)	Program the MUSE Headband that measures your EEG values to detect when you blink, focus, move arms.	Using MUSE SDK and Web Ble package for connection to browser.
Watson Vision and Text (training)	Uses IBM Watson Custom Vision Classifier to allow students to use vision and text models they trained in "Teach AI" section.	IBM Watson API Express server Watson Cloud Service for storage

Table 3: Cognimates extensions part 2

can be used in different fields, and how some of the projects could be used in the home environment.

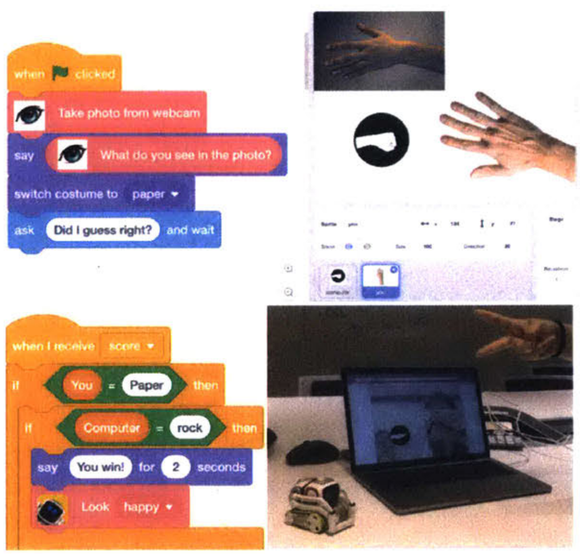


Figure 42: RPS Game Starter project with computer or with Cozmo

As part of the starter projects, we created a Rock Paper Scissors game. In order for the computer to recognize the gestures shown in the camera, children have to train a model by giving it 10 examples of pictures for each of the gestures. The more children play the game the better it gets at picking-up their gestures because it has more examples. Children also have the option to correct the computer when it guesses incorrectly and tell it what the correct gesture is. In this project, children learn about two main AI concepts: image classification and supervised learning.

While children loved the game after trying it a couple of times, they decided it would be much more fun to play it with a robot rather than playing it with a computer. To do, so they added the Cozmo Extensions and made Cozmo react as happy or frustrated depending on the game outcome (see Fig.42.

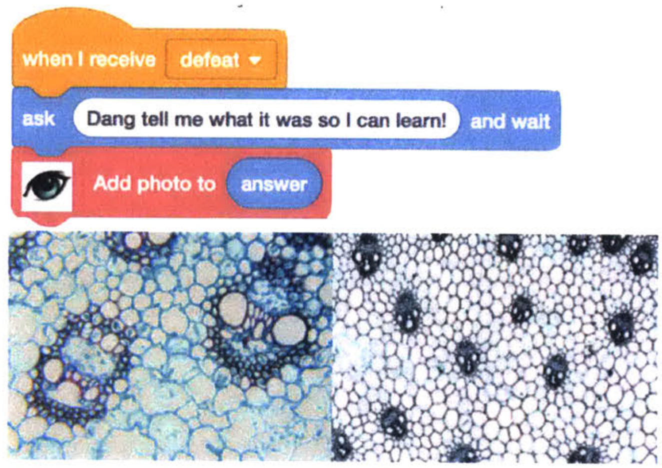


Figure 43: Microscope Starter Project with Custom Vision Model

We also showed children that they could connect an external web-camera in order to get camera images into their project. This allowed them to bring the camera very close to objects and transform it into a microscope. I suggested that they train a model to recognize their food from up-close, and they loved that idea. This example shows how the AI extensions can also be used in a biology and science class (see Fig.43).

Many children already have the Alexa smart assistant at home, and they were very eager to learn how to teach it things that they could continue to do so at home. In general, children loved playing with the hardware extensions to make the lights, a disco ball, or a bubble machine react to their voice commands by using the Smart Plug and Smart Lights extensions (see Fig.44).

5.7 LEARNING GUIDES

We want to encourage parents/teachers to use the Cognimates platform with their children/students. We developed a series of learning guides in collaboration with STEAM educators from MIT, Barcelona, Hong-Kong and Germany. Below is an example of a one-pager guide. The full list of education resources we developed is in the Appendix.

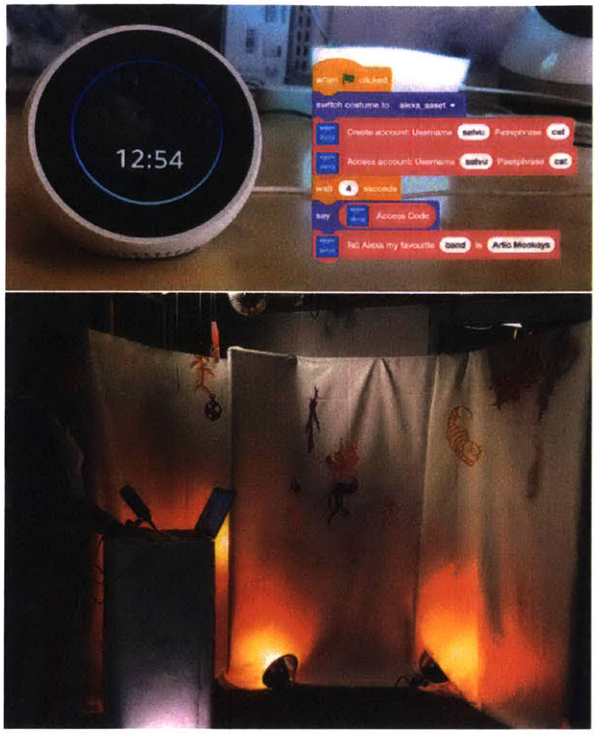


Figure 44: Smart Room and Alexa Starter Projects

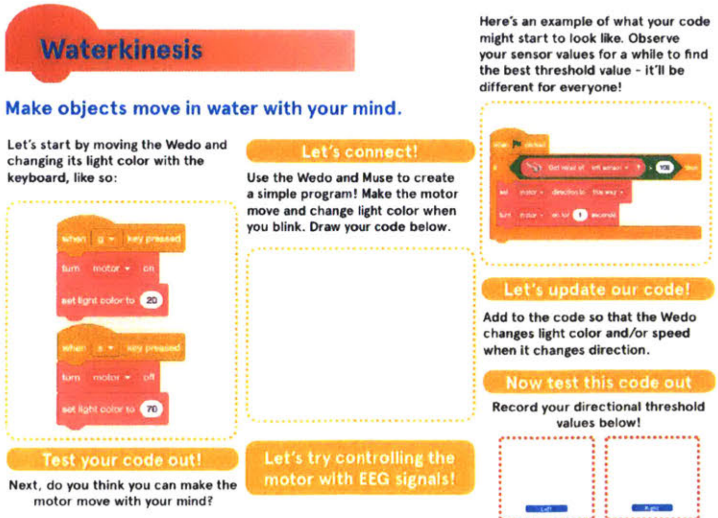


Figure 45: Waterkinesis activity guide

5.8 MISSIONS

The Codelab also has a series of missions for the Cognimate, Jibo and Cozmo extensions. The missions enable agents to act like learning companions and provide specific feedback to children based on the blocks they are using or encourage them to use terms and discuss what they did. The missions were initially designed for both a parent and a child to define and work within a shared conceptual space as they attempt to solve particular challenges [5]. Based on the observations from the first pilot workshops with families, I decided it is best to start by designing first missions mainly for parents and teachers who requested more scaffolding and support in using the platform. For the most part, children were more happy to explore on their own and felt the mission mode was too constraining.

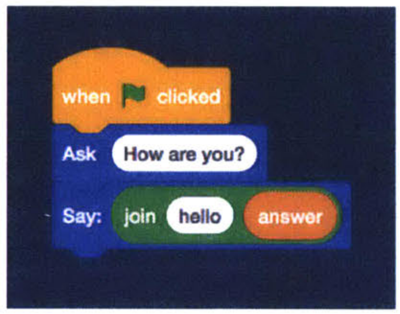


Figure 46: Example of code for the "Teach me your name" mission

```
var mission_name = {
  numberSteps: 3,
  steps : [
    {   init_blocks: [],
      end_blocks: ['event_whenflagclicked'],
      init: {text: "Hi there I would like to know your name, so let's do
          a program that allows me to learn it. Let's start with the
          green flag block",
      image: './playground/media/icons/event_whenflagclicked.svg'
      },ok: {text: "There you go! You did it!"
      },bad_block:{text: "ahhahaahh! you didn't use the magic block!"
      }
    },//part of the code removed here
    {   init_blocks: ['event_whenflagclicked','jibo_ask','text'],
      end_blocks: ['event_whenflagclicked','jibo_ask','text','jibo_say','
          text', 'jibo_answer'],
      init: {text: "Now use a jibo say block and drag inside the answer
          block.",
      image: './playground/media/icons/jibo_say_answer.svg'
      },ok: { text: "Cool! Now press the green flag button and see if I
          can remember your name."
      },bad_block:{ text: "remember to use the answer block!"}
    }
  ]
```

```
}
```

Listing 1: Fragment of the code for the interaction in the mission "Teach me your name"

Figure 47: Cognimates with Jibo in mission mode

5.9 PLATFORM ANALYTICS

Because the Cognimates platform has been available online for free since February 2018, it has been used in more than 35 countries, by 816 active returning users, that spend on average 20 min per session.

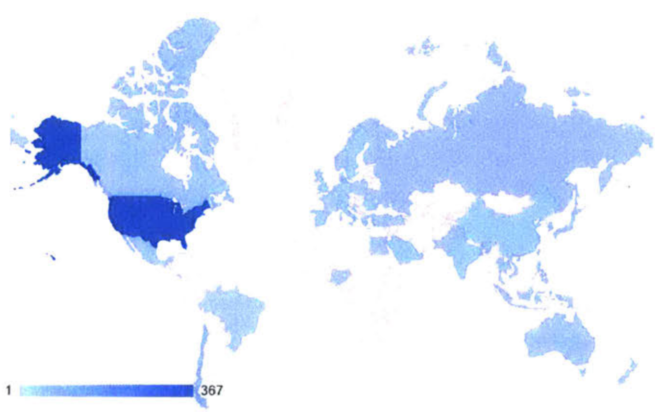


Figure 48: Maps of Cognimates users around the world, 816 unique users, 2063 sessions, average session time 20 min.

5.10 DESIGN PRINCIPLES

When designing this platform, I took inspiration from the principle of "Low floors, Wide Walls, and High Ceilings" proposed by my former advisor, professor Mitchel Resnick [53]. I built on his experience and the example of the Scratch platform. I added a series of guidelines inspired by my experience of working on S.T.E.A.M education with children over the years, and the numerous coding workshops I ran with children in the past 2 years.

- **Low floors, Wide Walls and High Ceilings**: include elements and features that are easy for kids to understand (low floor), but general enough to support diverse uses (wide walls), and add ways for children to customize and define new features (high ceilings)
- **Design for Tinkerability**: tinkerers start by exploring, experimenting, and think with materials. To support this style of interaction, I designed our interface and extensions to encourage quick experimentation and rapid prototyping cycles.
- **Design for collaborative scaffolding**: allow children to do both individual and collective activities (e.g., train an AI model together, use it in individual projects) and remix and build on each other's work (both projects and AI models).
- **Design for playful debugging**: children learn to break and fix things – provide ways for them to do playful debugging (e.g., confuse the AI models, make the robot go in a loop, make the computer talk to itself).
- **In the shoes of the agent**: allow children to see how the agent (or the computer) sees the world or makes decisions, so they can better understand how it works.
- **Keep it weird (Child in the loop)**: allow children to express in different modalities (e.g., drawing, speaking, building something), how they imagine the future of these technologies, and build features of the platform to match or challenge their expectations.

5.11 THE ACTUAL "COGNIMATES"

I named the platform "Cognimates" as a tribute to Edith Ackermann's research and work on "Animates", or "Play things that do things" [1]. Edith together with Sherry Turkle were the first to explore how children engage and interact with smart toys (as discussed in related work section). Edith's framework for establishing what allows a toy to be considered an "AniMate" served both as a guideline, and inspiration for how I designed the Cognimates platform. At the time, the "smart toys" were not as advanced and prevalent in children's homes as they are today. The goal of this platform, and my thesis, is to build on their wisdom and research to unveil what are the new guiding

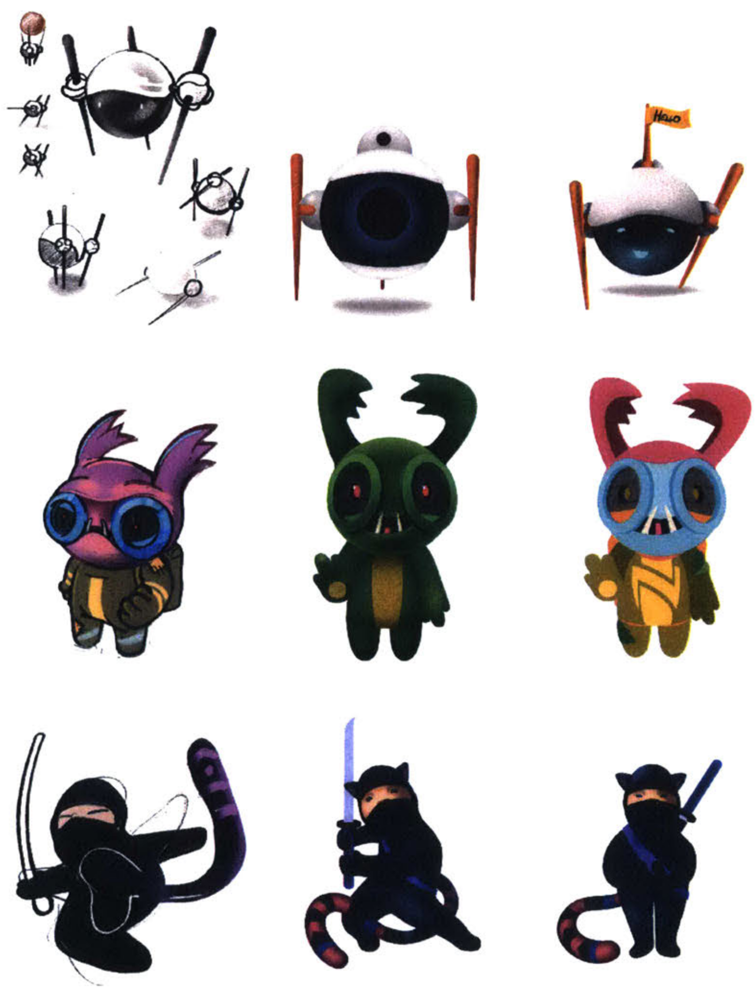


Figure 49: Example of Cognimates Codelab Characters: Eyeball, Nary and Ninjat design iterations based on children's feedback

principles when designing for this generation which is growing up with AI.

Initially for me the Cognimate was an embodied intelligent agent that children could program and teach. The agent would be both a friendly companion(playmate) and an object to "think with" and learn with (cognimate). The idea was also to design a platform that would allow children to connect multiple of their computational objects and make them interact with each other (Cognimates) (see Fig.50).

Figure 50: Examples of Cognimates Physical characters created by children for their coding story: Jibo as an Ogre and Cozmo as Frog prince

As we ran workshops with children in schools, we realized that they would refer to the digital characters (codelab sprites) as a Cognimate also. When talking about the projects they did, and concepts they learned, they would refer to the "make Nary happy" project rather than feelings detection or sentiment analysis project. This encouraged us to create many more characters that could embody and manifest what the different AI extensions do. Some characters like Nary could express different emotions to express if the computer detected a happy or sad message (see Fig. 51. Other characters would change color to show the computer recognized a specific color, we also made a giant eye for the vision extension to show what the computer is recognizing or if it gets confused. All the digital Cognimates come with the starter projects listed in Appendix.

During our studies, we observed that many of the concepts and inner workings of AI systems and smart agents are too abstract for children. When children are programming with a cognitive service, the digital Cognimate manifests and enacts how a this service works (e.g. learning how to see or speak). These characters aim to create powerful analogies and conceptual bridges while allowing children to used them in relatable stories.

Figure 51: Examples of expressions of one of the digital Cognimates characters, Nary

Below I list some of the "hidden" qualities that endow an "Cognimate" with the ability to draw children in, keep them engaged, amuse them, and become "objects to think with" about AI :

- **1."Otherness"** - These computational objects are transitional between physical and digital world, animate and inanimate, which sometimes display a volition of their own and inner life. They allow children to teach and program them without becoming assimilated.
- **2. Artificiality** – The child knows the agent is not "really" alive. The artificiality of Cognimate enables the children to engage in ways not possible with people or pets and explore liminal boundaries.
- **3. Believability** – The child sees that the agent exhibits strange yet a believable behavior. The Cognimates's personality and consistency in manners of being and doing, creates opportunities for playful exploration of issues of identity and attachment for children.
- **4. Friendly** – The child perceived the Cognimate as a friendly presence that engages them in dialog and play, at the same time, maintaining its distance.
- **5. Programability** - The Cognimate allows the child to program it and teach it things.

In sum, the "otherness", artificiality, believability, friendliness and programability of a Cognimate can lead to very rich psychological reflections, such as agency and identity, and issues of control and communication beyond helping children understand how programming and AI works.

6 AI EDUCATION IN EAST SOMERVILLE COMMUNITY SCHOOL

> "All of this is human intelligence programmed into the machine" - Sonia, 10 years old

Figure 52: East Somerville Community School students discovering the agents in the first session

The first long term study took place in the East Somerville Community School, a Spanish-English bilingual public school with mostly children of modest immigrant families. Of the 27 participants(16 boys and 11 girls), 17 (13 boys and 4 girls) completed all the study sessions. Of those who completed the study, 8 participants were younger, (7 - 9 years old) and 9 older (9 - 14 years old)[4]. Most of them had very little prior programming experience and only half of the older boys had programmed with Scratch before.

6.1 PROTOCOL

The study comprised of 4 phases: introductory phase, initial encounters with agents and perception, programming and training AI and a post-activity test. In the introductory phase I wanted to establish a baseline of children's intuitions and exposure to AI and programming. The initial encounter with agents phase was used to gather interaction and perception data. The programming and training phase allowed participants to better understand how these technologies work by doing. And the final post-test activity recorded how their perceptions of AI changed from the first encounter phase.

All the names of children used in describing the results or paraphrasing quotes were modified to protect their identity. All the sessions were run by the author of this thesis and her team of undergrad interns who had received the appropriate IRB training and approval. The team of researchers was consistent during all the study sessions.

6.2 INTRODUCTION SESSIONS

The introduction sessions started in February, with three school visits where the team, based on meeting a group of 6 students (6-8 years-old), assessed the children's initial knowledge about AI and programming in order to determine the complexity and duration of the subsequent study. The children were asked to explain if, when and how they heard of AI before and to describe how it works and what they would like to use it for. Some of them drew talking boxes (see first drawings in fig 53), while others drew robots or computers.

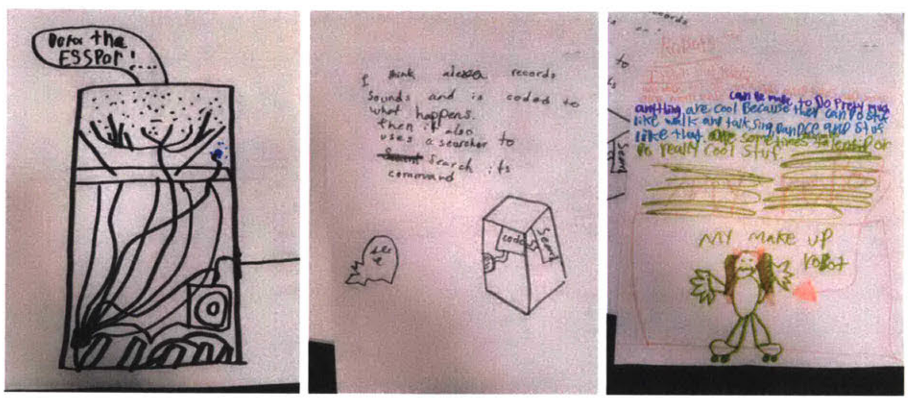


Figure 53: Drawings of children imagining their own future AI agents: Dora the explorer, Alexa Search Box and Skater Robot

Lara, a 7 year-old girl who made the drawing of Dora the Explorer AI, described it as a "CD that would store everything. And this is the main unit, and this is the plug into the wall, then these are the dots"(pointing at the drawing)(..) "so the dots that you don't see the lines connecting to those are the dots that you speak into but the dots that they are connected to those are the ones that it can talk". When asked how one could connect the dots that were not connected, Lara replied: "So, like, we will connect them by different wires going to a different place," while another boy (6 years old) asked "But they are like somewhere in the back, right?". I then asked Lara if she thinks her machine could learn how to connect those dots. She replied "Yes, I think so". The same boy then suggested: "Maybe you can make it do it. You could say Alexa, connect the dots "beep beep beep" and extend wires as you go." I then asked all the children if someone would have

Study Phases	Participants	Structure
Introduction Phase 1 Session	6 participants (3 boys and 3 girls) Ages: 6-7 years old	1. Exploratory discussions about AI and its applications 2. Imagine and draw your future AI or robot 3. Explain how it works and what it can do
Initial encounters with Smart Agents 1 Session	27 participants (16 boys and 11 girls) Ages: 6 - 7 years old - 6 children (3 boys and 3 girls) 7 - 9 years old - 10 children (7 boys and 3 girls) 9 - 14 years old - 11 children (8 boys and 4 girls)	1. Interact with 3 different agents (Alexa, Cozmo, Jibo) 2. Program the agents via their coding apps (for Cozmo & Jibo). 3. Ask questions about children perception of the agents
Programing and training phase 4 Sessions	23 participants (14 boys and 9 girls) Only 17 complete full study (13 boys and 4 girls) Ages: 6 - 7 years old - 6 children (3 boys and 3 girls) 7 - 9 years old - 8 children (6 boys and 2 girls) 9 - 14 years old - 9 children (7 boys and 2 girls)	1. Discover and test starter ai coding projects for Cognimates 2. Complete 3 learning guides that help students train their own classifiers with text and images 3. Create their own projects and new AI training models
Post-test activity 1 session	17 children (13 boys and 4 girls) Ages: 7 - 9 years old - 8 children (6 boys and 2 girls) 9 - 14 years old - 9 children (7 boys and 2 girls)	1. Ask questions about children perception of the agents 2. Conduct interviews to asses childrens' understanding of AI concepts

Table 4: Protocol East Somerville Community School study

to teach Alexa how to connect the dots. All five children replied, with enthusiasm, "Yeah" and Lara concluded by saying " maybe I could do it by code."

Later on in the conversation, the children continued to use the wires and dots analogies in their reasoning and explanation. One other boy Bill, 6.5 years old, said when describing his Alexa Search Box drawing 53: "I think Alexa records sound and records what happens and then the dot searches for the sound through its searches command like if you say search for music then it will search for music" (so it records sounds?) "Yeah it records sound and then it sends the message into the code and then that reads the code then it knows what to do and then it searches for what to do". When asked where the code lives, the children came up with all sorts of different answers: "in a chip", "hard drive", "motherboard","in the TV","in the disk drive". When asked if they have heard of the Cloud, all the children answered affirmatively. I then explained to them what a data-center is and how it has many big computers that can do all the searches that they are describing.

We then discussed about other examples of AI, such as self-driving cars and how they need to recognize traffic lights, traffic signs and other cars. Bill told me that "cars can actually go somewhere when somebody needs a ride home". As the children all seemed to know about Uber and Lyft, I asked them how they think these ride-sharing applications find the shortest path from my school to their school. Lara answered by saying "so it's something like training a cat, and every day it practices stuff to understand what to do like I'm training my cat to high-five me". I asked them, in return, how one might motivate the cat to learn. They said they would motivate the cat with food. Then I asked them how we might motivate the cars to learn, and what would the food be for cars *food*. All children started discussing vividly all sorts of ideas. I then explained to them that if "cars don't go on the right path, there's a code that tells them that they are not getting any rewards, and if they go the right path, they get more rewards like candy–but in code and this is called Reinforcement Learning." The children loved the explanation and continued to debate more ideas about candy for cars. It was very interesting to observe that they wouldn't shy away from technical terms and many of them already knew of complicated terms such as "motherboard" or "hard disk".

Sophi, the 6-year-old girl who drew the Skater Robot described it as "a dream robot" that would help her with math. And "if I got hurt, it would help me and it would make food for me." Jimmy, another 6-year-old boy, drew a Lego robot. When asked what his robot does he said "I program it".

The conversation continued as following (the researcher questions are italicized):

- *But could you make it talk to you?*
- Jimmy: Well, I actually can when I program it.
- *How do you talk to it when you program it?*
- Jimmy: By code, technically.
- *What if you could control it by a voice? If you tell it "robot, move" and the robot starts moving*
- Jimmy: Yeah, but he doesn't know which way to move so you have to make it specific. (..)
- Bill: Or you can say "Robot, recharge your battery!". And then he would do recharging
- Multiple participants: Doo doo doo doo doo! (recharging noises)
- Jimmy: What he would do is walk over to the recharging station and "beep beep beep beep." And then he sticks it into him and "beep beep beep beep! I'm all done!

This conversation shows how much the children were scaffolding and building on each others' ideas and explanation while exploring through conversations their basic intuitions on how the technology that surrounds them works and how it could evolve in the future. From a research or educational perspective, I think it is important to play along with the words and analogies children use (e.g. wires and dots) and continue their logic thread by asking questions that can enable them to find their own definitions and explanations. Having a physical artifact such as a drawing in this case, or a physical prototype, can help the children better explain and reflect on their own reasoning.

From the initial conversations, we can see that children conceptualize AI primarily by comparing it to a computer and to their knowledge of how a computer works (using it's chip, memory, wires). If the device talks, they say it can and will be programmed via voice (here they refer to programming more like controlling). We also see that children don't have a natural intuition about how AI systems use data and learn from it, but they can conceptually understand how that works. I expect their theories about AI and robots inner workings to become more complex and include the main idea of feedback loop and learning from interaction once they get to program and train their own AI with Cognimates.

6.3 INITIAL ENCOUNTERS WITH SMART AGENTS

After the initial pilot sessions we started the long-term study by introducing to children three different embodied intelligent agents: Jibo robot, Anki's Cozmo robot and Amazon's Alexa home assistant 54. Each agent was placed on a different table and the children were encouraged to form groups and take turns in interacting with each agent. First, the researchers would demonstrate the vocal commands for activating each agent (e.g. "Hey Jibo" or "Alexa") and some of its capabilities. Then the children were left to explore on their own, using both the voice and the bundled interactive applications. When the children were stuck, the researchers would demonstrate new capabilities or ask questions to help them debug.

After the initial play and interaction, children were also encouraged to program the agents using the existing commercial coding apps developed for each agent. I was involved in the development and research behind the BeAMaker application used for programming Jibo. All the coding apps deployed at this stage of the study used a visual block programming language based on Scratch Open Source Blocks and were comparable in terms of design and complexity.

Figure 54: Agents used in the study: Jibo robot, Anki's Cozmo robot and Amazon's Alexa Echo spot

Children liked the Cozmo robot the most. First, they started playing with Cozmo in explorer mode, controlled it by tele-operating it via a phone or a tablet. The robot was able to recognize different objects and people (cube, faces that were taught to him). When the children saw and realized that Cozmo was able to pick up a cube it had just recognized, they became amazed. The team prompted them to think about how Cozmo is capable of recognizing a cube: is it because of the camera, or does the cube send a signal? The children were asked also to think how one might test these hypotheses. Because Cozmo only talks with a robot-like voice, which is hard for the children to understand, they did not spend a lot of time making it to talk.

Because the robot was able to express a will of its own by moving around and manifesting various expressions when it comes to life after being connected, many of the children thought that the robot was mocking them or was responding to their actions. They tried to guess and probe how exactly the robot did what it did. After playing with the Cozmo in explorer mode, we encouraged the children to

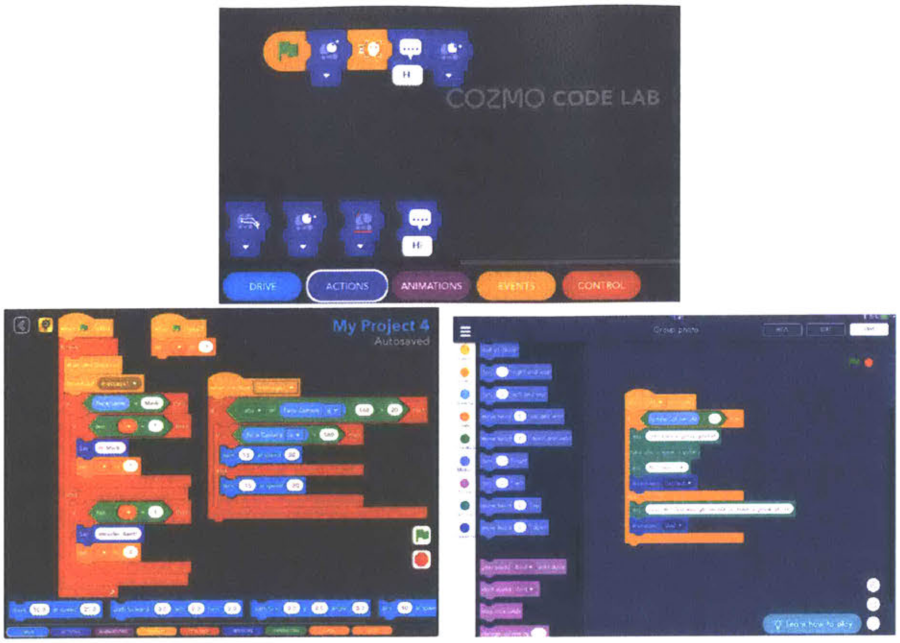


Figure 55: Coding interfaces used for each agent: Anki's Codelab (horizontal and vertical blocks) and Jibo's Be a Maker

program Cozmo. When the children didn't know what to make the robot do, we would ask them to make the robot draw various geometric shapes like a square, circle or triangle with its motions. In order to better visualize what the robot does in contrast to the expected behavior, very often we would attach a pen to Cozmo and put a paper underneath so the children can more easily visualize its movements. Other times we would ask a child to pretend to be a robot while the others would give him or her commands to move in order to better understand what algorithm they would need for drawing different geometric shapes. This kind of exercise is always a lot of fun for kids and draws on their body sintonicity intuitions as shown in the early work of Seymour Papert on logo and Turtle geometry.

Figure 56: Cozmo Explorer interface

While many of the children were fascinated by Cozmo's expressions and moves, they were also very drawn by the natural voice interface of Alexa and Jibo. Once they figured out how to talk to them (e.g. using the wake-up word) they would group around the devices

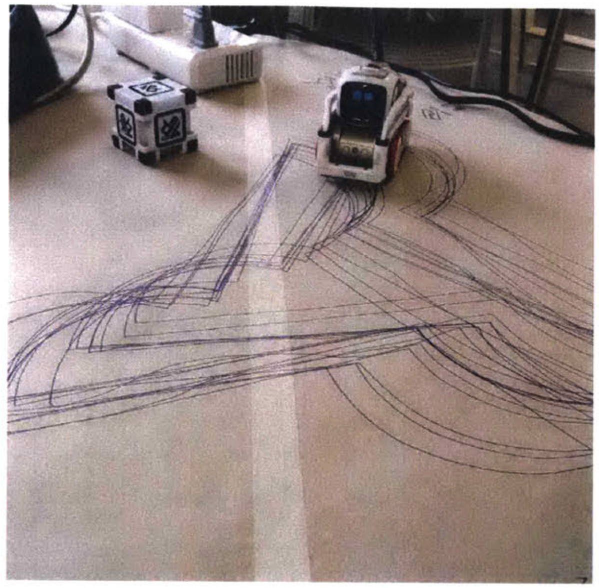


Figure 57: Cozmo Turtle Activity

and talk on top of each other trying to get the devices to play specific songs (the most common request), answer math questions, beat-box or speak other languages. Very often they would also ask the devices questions about the companies that created them or about the other agents (e.g. "Alexa what do you think of Google Voice?"). To the children, the most fun feature for Alexa was to beat-box, play music and take pictures, and for Jibo, play games ("Circuit saver" game) and take pictures.

The kids were reassured by the fact that these devices could not move independently as they were quite intimidated by the amount of information they believe the devices hold. It should be noted that the school had limited Wifi connectivity and due to this constraint,the Jibo robot especially would not always respond to voice commands–something that might have influenced children's perception.

After interacting with the agents, participants completed a ten question survey about their experience in the form of a monster game (see Figure 58).

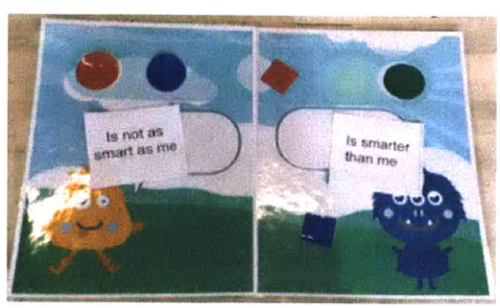


Figure 58: AI Perception Monster Game

The monster game was adapted from the work of Park in order to more effectively engage younger children in the questionnaire [47]. The two monsters each represented a belief about the agent. The children were asked to place a sticker closer to the monster with which they most agreed. Before asking the questions, the researchers gave an example of how to respond. We vetted the usability of this method and the clarity of the questions by pre-testing. Responses to each question were recorded as orange, blue, or neutral. The questions query how children felt about the agent in terms of trust, intelligence, identity attribution, personality, and engagement. We adapted the questions from the work of Bartneck based on the agents' attributes we wanted the participants to explore [6]. His work summarizes prior research on children's perception of robots, which I found to be suitable in this context for establishing a baseline for how smart, friendly, trustworthy, understanding and caring the agents were in children's eyes. I wanted to measure child's perception and opinions along these dimensions and compare how they might change once the children infer more about their inner workings after programming and training AI with Cognimates. Results for the perception-related questions will be discussed in detail in the quantitative and qualitative analysis sections of this chapter.

6.4 PHASE 3. PROGRAMMING AI WITH COGNIMATES

After the initial agents introduction and perception questions children were introduced to Cognimates platform where they could learn how to program, train and control these agents. In order to get them started I created the following series of learning guides and starter projects. We also designed and printed learning guides for these activities in order to encourage the children to reflect on their process and test to see if they understood the main concepts (see **??**).

For the children who were less experienced with Scratch we would start with very simple activities like "Make me Happy"(**??**). In this activity, the students had to teach the computer through the Cognimates "Teach AI" platform how to recognize good messages or bad messages. Once the model was trained with their examples the students could use it in a pre-coded starter project which would make a character on the screen or one of the robots react to their messages. If the message they gave was classified as "kind" based on the model they trained, the character or robot would be "happy". If the message was classified as "bad", the character or robot would be "sad". The "Teach AI" text models would require them at least 2 categories (e.g. "kind" and "bad") and five examples of text for each category. The text could be one word or an entire phrase. On average the text models would take 2-3 minutes to train.

Core activities	Ai concepts	Extensions used
Make me happy	sentiment detection	Sentiment
Rock Paper Scissors	vision classification reinforcement learning	Pre-trained Watson vision
Smart Home	speech recognition rule based system	Text to speech Speech to text Watson text
Teach AI text	supervised learning with text	Watson text
Teach AI images	supervised learning with images	Watson vision

Table 5: Cognimates AI coding activities

Figure 59: Example of text examples the children used to train Good/Bad model for classifying text

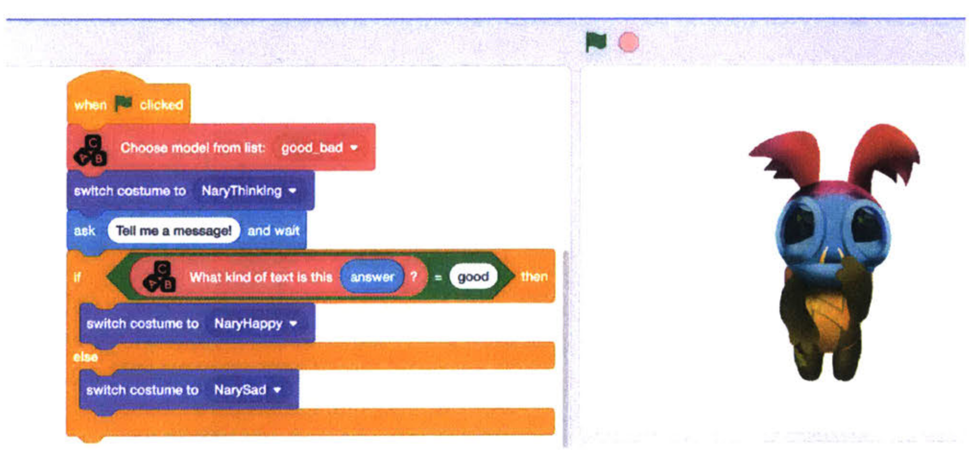


Figure 60: Example of "Make Me Happy" project using a trained Good/Bad model for classifying text

The more advanced children were encouraged to choose their starting activity. Most of the older children preferred to build an AI game first, such as Rock Paper Scissors or Crosses and Noughts. But they quickly discovered that training and programming a game to play such games with them was more complex and difficult than they expected. As a result, they decided to start with more simple projects.

The youngest group of children(6 children of 6-7 years old) also managed to create their own projects with Cognimates extensions and preferred to freely explore the platform instead of using our activity guides. They particularly enjoyed using the speech and the sentiment extensions. They loved making their programs talk, sing and rap. Lara (7 years old) did a more complex chatbot program that could change the background for each question asked. Unfortunately, this group of younger children had to join other after-school activities and could not continue to attend the Cognimates sessions and complete the study.

6.5 POST-TEST ACTIVITY

In the case of ECSC School, we were not able to collect final answers to the perception questionnaire after the programming phase due to numerous cancellations for the final session because of snow. When we did meet the children again a few days later we only conducted interviews and had a final discussion about what they learned, which concluded with a certificate of participation award. The interviews and reflections from the post-test activity discussions are analyzed in the qualitative analysis section.

6.6 QUANTITATIVE ANALYSIS

6.6.1 *What did children think about connected toys, intelligent devices, smart technologies?*

This section will analyze the findings from the initial perception questionnaire conducted during the initial encounters with agents phase of the study. I will also visualize and analyze the transcripts of children conversations in terms of the overall sentiment score, usage of technical terms and mentioning of agents in order to show how children perceived the agents overall and talked about them during the study.

The following table describes the demographic distribution of children who completed all phases of the study, whose data is being analyzed in this section 6.

Similar to our analysis of perception in previous studies, I observed several developmental differences. Just like in the first study we ran on child-agent interaction [16], younger children (7-9 years old) were

Students Young 8 Older 9 Girls 4 Boys 13	count	17.00
	mean	9.31
	std	1.92
	min	8.00
	25%	8.00
	50%	8.00
	75%	10.00
	max	14.00

Table 6: Table of Participants Age and Gender Distribution in ECSC School Somerville final perception study

more skeptical about the agents' abilities to remember them, to be smarter than them or to tell the truth while the older children (9-14 years old) thought the agents could understand them better than the younger children did (see Figure 61).

The children's answers were also influenced by how they perceived the meaning of questions, and some of the more inquisitive children like Jamir would often ask clarifying questions "What does it mean to remember me? Like see my picture or recognize my voice or actually know who I am?". Another child would say "Hm...let me think. It can remember you by like how you look like but not like your voice and actually remember you. So I'm gonna put it in the middle".

Other children decided that if Alexa, Jibo or Cozmo took a picture of them it would remember them. Sometimes children would say the device will remember them only if they own it: "I think Alexa will not remember us because we're not her owner". When asked what would happen if they become the owner of the device another child would respond "he will remember you because I'm pretty sure just like Siri you can tell her your name to like ask her to remember you like who you are. Because you can tell them your name".

When comparing different agents, the children said that Cozmo understood them best, primarily because they could directly control it and program it. Alexa was seen to have occasional understanding, as sometimes she would have time picking up on their accent or expressions. Finally, Jibo was seen least understanding(this could be due to limited Wifi connectivity as Jibo's speech detection requires good connection to work reliably). They saw Alexa as the smartest agent, and therefore believed it would always tell the truth. When it came to Cozmo and Jibo, the children decided that maybe they tell the truth but depending on how the agents are being programmed or controlled. Children described the agents that had a camera (Cozmo and Jibo) as more likely to remember them.

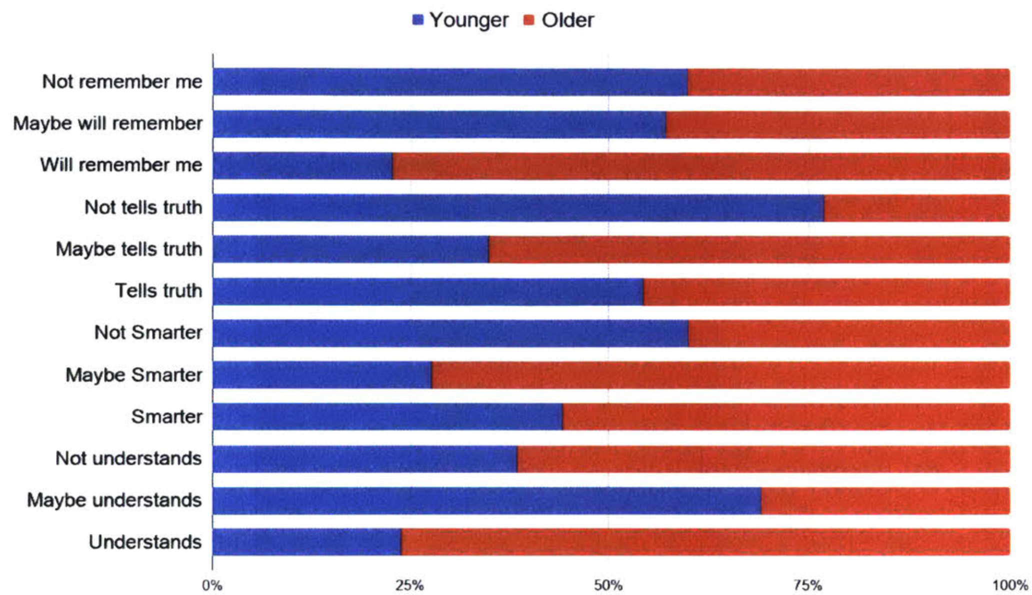


Figure 61: Summary of children answers to perception questions aggregated by age

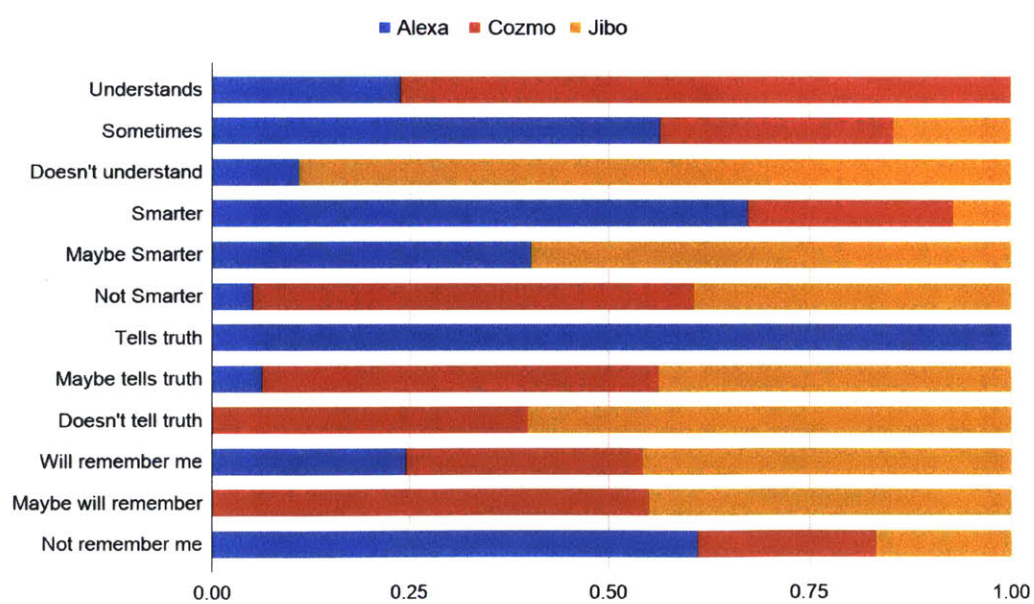


Figure 62: Summary of children answers to perception questions about the agents

6.6.2 *Sentiment Analysis on Children Conversations*

As we recorded and transcribed several hours of conversations that children had when interacting with the agents and participating in the perception questionnaire I wanted to get an overview on their attitude (sentiment) and language towards these technologies. Looking at the most common positive terms can reveal if children are expressing a mere fascination with this new technology (e.g. terms like "like", "awesome") and which aspects of the agents they like the most (e.g. "friendly", "smart"). Looking at the most prevalent negative terms can show which aspects of the interaction frustrated the children the most (e.g. "ignore", "indifferent"). Another reason why I wanted to code the conversations transcripts for word frequencies is to discern the usages–and their frequency–of technical terms and AI concepts.

After processing and cleaning the transcripts (removing participants' names and file names), I used several existing libraries and models to analyze the sentiment of the children's words. The first library I used was AFFIN, a curated list of words rated for valence with an integer between minus five (negative) and plus five (positive). Sentiment analysis is performed by cross-checking the string tokens(words) with the AFINN list and getting their respective scores. The comparative score is calculated by dividing the sum of each token sentiment score by the total number of tokens [43].

For the transcripts from East Somerville Community School, the average AFFIN sentiment score was 153.5 and the average comparative was 0.059075621385, indicating a mostly neutral conversation. In order to better illustrate these results, I created a series of word clouds 63.

Figure 63: Word clouds generated from the transcripts of children conversations during the study (interaction and coding time): Positive terms, Negative terms, All terms

I validated the AFFIN results by also analyzing the transcripts with the NLTK (Natural Language Toolkit) library, which is using hierarchical classification for each word. Neutrality is determined first, and sentiment polarity is determined second, but only if the text is not neutral [9]. The NLTK results for our transcripts were the following:

0.03 negative score, 0.798 neutral score, 0.172 positive score. Overall the text sentiment polarity was of 0.18 and the subjectivity was 0.50.

The most mentioned agent names in children's conversations was "Alexa" with 38 mentions followed by "robot" with 23 utterances, "Jibo" with 11 and "Cozmo" with 8 64. The fact that children mentioned Alexa the most in the conversation doesn't mean it was their favorite agent, because in most cases they preferred the social robots (Cozmo and Jibo) as also shown in the perception figures (see 62. I think children mentioned Alexa much more because it has an easily relatable name and was the agent that could engage in conversation with them the easiest (both in its human-like voice and its speech recognition performance). Because of these attributes, children would ask Alexa more questions, and based on the answers, debate more what the agent thinks or how it works.

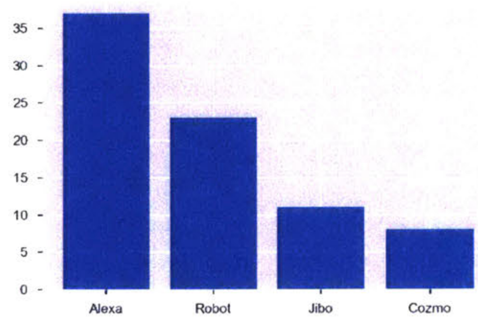


Figure 64: Agent mentions in conversation transcripts

6.7 QUALITATIVE ANALYSES: CASE STUDIES FOR A DEEPER LOOK INTO HOW CHILDREN LEARN ABOUT AI BY MAKING

The majority of the children that participated in the full study changed their attitude and perception of AI technologies and devices after understanding more about how they work through hands-on Cognimates projects. These changes were recorded by analyzing children interactions, conversations and projects. They are discussed in detail in the following section by analyzing the experience of both younger and older children. I choose to present both examples of younger and older participants because I found strong developmental differences in the way children in these age groups perceive the agent (especially its intelligence and its trustworthiness) and in the way they collaborate (older children are much better at pairing and helping each other).

We had 8 younger participants (7-9 years old) and 9 older (9 - 14 years old) ones who participated consistently in this five-week study. Out of these participants, I would like to illustrate stories and learning trajectories of children with various ages, genders, technical backgrounds and personalities. The goal of these mini-case studies is to show how we can better design AI learning activities for different children and engage them in different ways.

6.7.1 *Younger participants*

When analyzing younger children's interaction with and perception of AI before and after programming and training activities, I found that younger students overall had a harder time engaging first with programming AI if they had limited or no prior experience coding. In this case, starting with interactive activities, where they could just teach the agent or the computer by showing it examples of text and images, worked best.

> "Cozmo might not like me very much because I made him do things he might not want to do" - Larry, 7 years old

Larry: Coding robots while carrying for them

Larry (7 years old) was an introverted, shy and quiet child and a first-time programmer. He had no experience with Scratch but learned very quickly to program the Cozmo robot to move and turn. He also built a lot on his math questions for Alexa after seeing a demo from the researchers. Larry enjoyed programming had a strong connection with Cozmo, but, from time to time, he would stop and say "Cozmo might not like me very much because I made him do things he might not want to do." Here we observe the tension created by the animated agent in the child perception. Just as Edith Ackerman explained, the "AniMates" toys or things bring children in by being both artificial and relatable, believable yet surprising in their behavior [1]. In the case of Larry, we clearly see how he got interested in learning how to program because he really likeed this little expressive robot toy (Cozmo) and wanted to make him do different things–and at the same time he was conflicted because he didn't want to upset the robot by controlling him. This example, as I see it, captures a fundamental question: how will children engage with social robots and smart toys in the future? How will the locus of agency be negotiated? How do we ensure that children maintain and develop a healthy level of empathy, attachment, respect and civil conversations with these devices while also cultivating a sense of criticality and agency towards them? From a design perspective, we can further explore what a robot's or toy's reaction should be when it's being programmed so that the child knows that it is okay to take turns in controlling the device but also learn from it and let it manifest its characteristics.

When being asked to imagine his own AI, Larry drew an elastic futuristic AI (Stretch) than could fold clothes, look up on a computer and detect lost things. He wanted to teach it to do back flips by giving him instructions as he would give to a human and practice until Stretch could back-flip. He imagined the robots to grow and transform :"Maybe the robot can transform and do what you say..." he then gave a transformation example for when robots grow taller to grab things from high shelves. In this example we see a common trait observed among younger children who aspire to have robots and AIs that can help them do things that they cannot do yet (reach high shelves), do things that are hard like math and homework, do things they don't like to do, such as going to school (many children mentioned they would like to send their robots to school for them), or to protect and help them when they are not feeling well or safe (see also example of younger girl who drew the Skater robot 53).

When being asked how Alexa looks up stuff, Larry said: "Maybe because Alexa is a computer but a different type of one and she can probably go into a computer with um maybe Alexa and a computer have the same pass codes so Alexa can just go in the computer and when you tell Alexa what to do she'll bring it up". Here, similar to the "dots and wires" analogy from the pilot sessions, we see the importance of letting children explain and imagine how these devices work in their own words. Researchers, teachers and parents can then reference the same terms and ask more questions or provide further contextualized explanations that the child would care about because they are based on his inner intuitions and logic.

Larry became interested in the age of Alexa after asking it many math questions. Upon discovering that the device was created three years ago, he said: "she's three years old! Oh my gosh, she(Alexa) is three years old! And in dog and cat years she's 28! She's young!"

When asked if the agent is smarter than he is, Larry replied: "Alexa is definitely smarter than me she can do all kinds of math that I don't even know the answer to." He also added: "I think Jibo is more like an animal because I don't think it can do a lot of math". Multiple children expressed their fear for mathematics and were truly convinced of Alexa's intelligence once they saw how it can easily solve any math problem. However when being asked who taught Alexa how to solve the equations, some of them changed their answers and said that Alexa is not smart, but the people who programmed it are.

When asked if the agents will tell the truth, Larry said: "Alexa will always tell the truth because she's very smart" but "Cozmo might not always tell the truth because he doesn't know the answer" - and when asked if Cozmo doesn't tell the truth on purpose or by accident he replied "probably by accident because he's not as smart". Here we observe a very important trait in child perception of smart technologies which appeared in other conversations with children in this

Figure 65: Cups vs Cars vision model that Alex trained

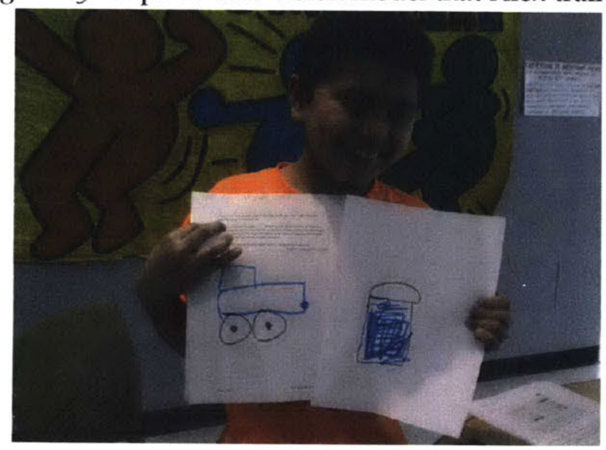


Figure 66: Alex holding the drawings he made to test his model

study: if they perceive the device to be intelligent, they trust it fully. The more they see that they can program and teach the device, as in Larry's case with Cozmo, the more they tend to consider the agent less smart and less trustworthy.

Alex: channeling the hyperactive children

> "Alexa is a she right?". - Alex, 8 years old

Alex, 8 years old, was one of the most engaged participant yet most hyperactive. He had no prior experience in coding, nor an interest in doing so. However he loved to interact with robots, pre-trained Cognimates games and other AI applications like "Teachable machine" or "Quick Draw". Alex became interested in training his own AI model with Cognimates only when he realized that would enable him to play more games like the ones he enjoys but by using his own drawings and objects around him.

He really liked cars so he decided to train a model to recognize cars and spent a long time selecting images online of all sorts of different models and colors. When asked what he will compare the cars with, he decided to use cups because he said he is not very good at drawing and it would be easier for him to draw cups. Despite the fact that Alex would become very frustrated with the computer every time it would get a prediction wrong, he kept on trying to make it better by adding new images or to change his drawings to test if it really works. He tried to see if adding wheels on a cup would make the model recognize it as a cup or car. Or if changing the color of the cup so it's not "black like the car tires" would also make a difference. He also convinced Kiara, a 9 years old girl, who was wearing a t-shirt with a drawing of a hot chocolate cup to come and test his model. When she protested that what he is doing is weird he replied "it's only weird if you make it weird" and explained that he really needs the image for his model.

Adding more images to the model to improve the result was not a solution that came naturally to Alex. But after the researchers encouraged him to do so he spent more time figuring out what other images he could add. Only towards the last session, he realized that he was testing the model with drawings but only had images of real objects in his data and that was why the predictions weren't so good. In the cases of children like Alex, high-energy and impulsive, the AI education platform and its curriculum need to lend itself for quick and interactive demonstrations to allow them to gradually modify and improve. It was crucial during the study to let Alex not just to switch activities or take a break whenever he wished, but also show interest and inquire about all the different projects he was trying. We also encourage him when he got something to work. Over time, Alex became more engaged, focused, and less disruptive to his peers.

During the perception questions, Alex did not change his answers after hearing other children's arguments. He also got annoyed when other children change their answers and said they are copying him. When asked if Cozmo will remember him he answered "he'll remember me because he's a robot and robots know everything and they can remember anything". At various moments during the interaction with Cozmo, he also asked if the robot "was mocking him" because he couldn't understand its reactions. When talking about the other robot Jibo, Alex explained how it will remember him "Because you know how he can like take pictures of you (..) so he has like a bunch of memory in his system". He also thought Alexa was smarter than him because "if you ask it things it will give you the right answer like whats 0 divided by 0's". As for Cozmo and Jibo, not smarter "because you can control them," according to Alex.

Alex was also very sensitive the question of gender. Several times during the study, he asked "Alexa is a she right?". When Sonia, an older girl, was explaining something to another younger boy, he called his name and asked him to show her who is the man. The other younger boy said she is bigger than him and he is not a full-sized man yet. This makes me wonder how kids who grow up in households where the women are portrayed and treated differently than men will perceive and treat smart home assistants that came with feminine names and voices.

When asked how he imagines AI in the future, Alex said he wants the AI to "be happy and live life (..) to feel free and choose if it wants to answer a question or not", he later added "like I tell it to do it and he has a choice to do it or not". We see here how he assigns a masculine role to the AI and identifies with it. In a sense just like the children who wanted the robots to do things they could not do, Ariel wanted his AI to be free and have choices because he feels constrained in the school environment.

Towards the end of the study, Alex's brother also joined. I asked Alex if he is going to continue to teach his brother at home how to use Cognimates, they told me they have a MAC computer at home but they are not allowed to use it.

Jamir: the mischievous hacker

Jamir was an inquisitive, resilient , but also mischievous child. He was a great team player–always helping others as he was much faster at typing or explaining how something works. Due to a technical issue in the first coding sessions, Jamir lost his "Make me happy" model three times. Although he became slightly frustrated and started to make jokes on how this "makes him happy", Jamir persevered and rebuilt the model every time while adding more and more funny examples. At some point, he realized he could access other children's previous examples by pushing the down arrow in the text entry fields and he started to explore that on all the computers and shared with the other students. He also would enter codified text like "xX CAILLOU xxXX" in his models, which is a common practice for children who communicate online 59.

After completing all the Cognimates guides, Jamir started to train his own new models to capture and express his sense of humor. He trained a model that could detect a weird hairline in pictures and became very creative about getting screen-shots from videos because he couldn't find enough images online to train his model.

6.7.2 *Older participants*

Older participants were similar to young participants in the sense that they all loved computer games but the older ones were more able and therefore willing to program their own AI games with Cognimates. Both younger and older students would experience an "aha " moment when training their own text or vision classifiers. But the

Figure 67: Jamir and Jose taking turns while pair programming

Figure 68: Weird hairline vision model Jamir trained

older students were more likely to use their model in a coding project. What differentiated older students from younger students the most was that the older ones collaborated more, paired and took turns on projects while building on their strengths.

Sonia: Falling in love with robots

It was Sonia's first encounter with robots and coding. She is ten years old and very outgoing. Despite the fact that she had little prior exposure to these technologies, Sonia was adamant about the robots not being real or having feelings. During the various study sessions she kept on emphasizing how she wished that Cozmo had feelings because he was so cute, but always countered herself with the realization that he is programmable. She kept treating the robot like a pet and would hold it in her palm while talking to it, even if Cozmo couldn't talk back (see 69).

During the perception questions Sonia came up with the idea of asking Alexa for the answer to perception questions (e.g. "Alexa do you always tell the truth?"), which shows some level of attachment to the device. She did not probe Alexa's skills with math questions and was much more interested in making it play music. She wasn't sure if Alexa is smarter than she is and said the devices won't remember it. As for Cozmo and Jibo, she said they might remember her and have feelings.

During the coding sessions she didn't really understand how the Cognimates extensions work until she trained her own extension. Sonia, like many other girls participating in the study, showed strong interest in the social elements of the interaction with the agents–how they talk, how they express emotions, which also explains why she liked Cozmo so much. Despite her attraction and excitement for this features, Sonia was very good at recognizing that these social interactions were predetermined and coded into the devices. Towards the end of the study she described AI as "human intelligence" but codded into the machine.

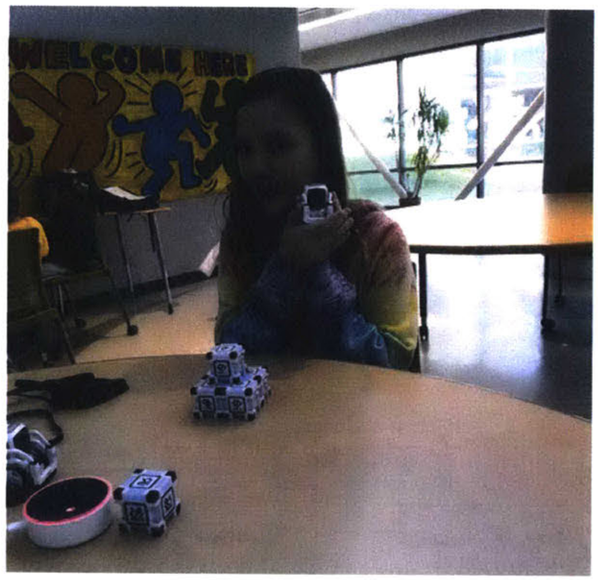


Figure 69: Sonia holding her favorite robot

Everson: the quiet coder

Everson was one of the most experience and oldest participants (14 years old). He told us initially he thought of AI as lines of code instead of robots. He has already been programming in Python but didn't shy away from programming with a block based language when he saw how many things he could create with the Cognimates extensions and that he could train his own models and use them in projects. Everson loved games so he wanted to start by training and coding AI games. When he realized that would be more complex than he had expected, he started first with and Owl chatbot project

He trained a model so the owl could recognize if the questions asked were about food, countries, lifespan or size of owls. He made the own speak both in English and Japanese and added a lot of humor to its answers (e.g. "Idk, I am a bot, stop asking me these stupid questions.."). He made the language of the owl sound like casual speak among people of his age (e.g. "alotta food XD")(see70).

Everson paired often with Daniel, another participant who was 12 year old. By the end of the study, they finished the most complex guides (Rock Paper Scissors, Noughts and Crosses) and started to think how they can make an AI game with zombies.

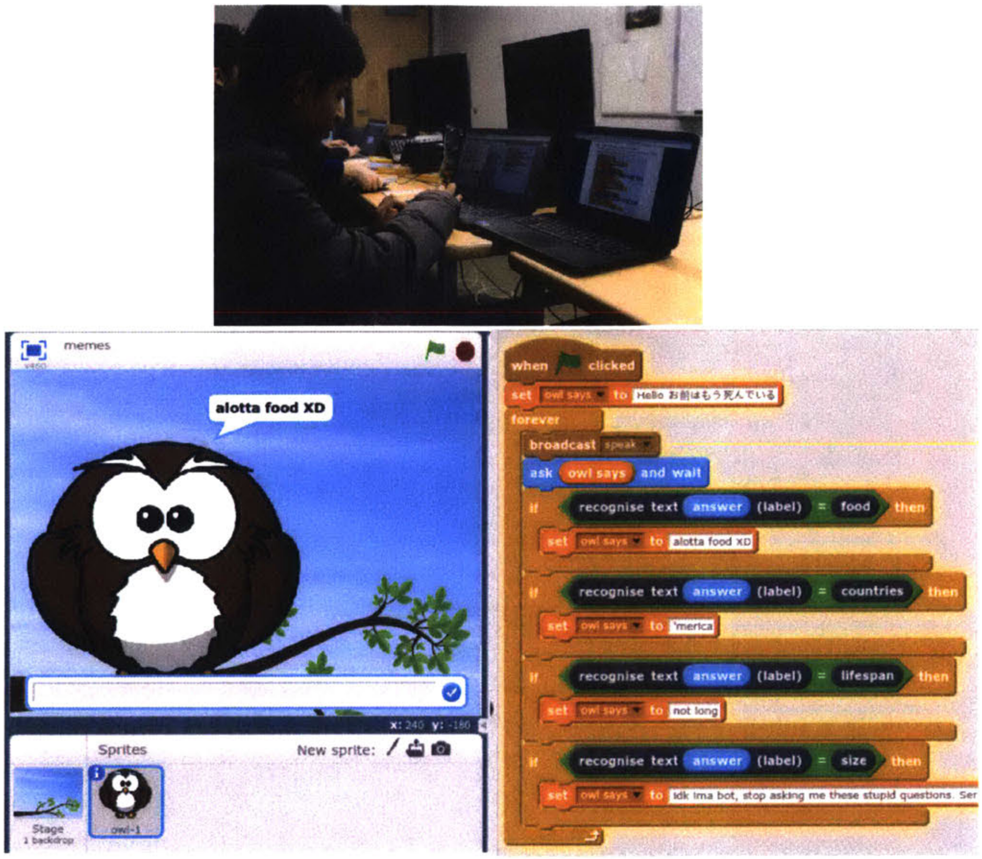


Figure 70: Everson programing his Owl Chatbot Project

Jose: Starting from Scratch

Jose, 12 years old, had no programming experience. He had a hard time with reading and writing but eventually became fluent with the Cognimates platform. During the study, Jose paired a lot with Jamir who was faster at typing and they would take turns in training models and coding games. Despite at the beginning it was challenging for him to understand how AI training works or how the blocks control characters or robots, Jose came to all the sessions he was assigned to and was one of the participants that progressed the most in terms of AI understanding and programming skills. Initially we thought Jose was frustrated because the projects were too boring or too hard for him. After we discussed with the after-school coordinator, we learned that Jose is not very good with anything that has to do with text; but if it is something visual, he will engage and try very hard to learn. I later discovered that this was the coordinator's way of saying that

Jose didn't know how to read and write, which explained why he refused to fill out any of our study forms. Jose's attitude and self-trust significantly improved after he saw he could program,train and control the computer and the robots–using images or voice.

6.8 ANALYSIS OF COLLABORATION AND ENGAGEMENT

In terms of project implementation, all the children completed the study learning guides and got the chance to play with other AI learning platforms (see the case of Alex) or create more complex projects after (see the case of Everson or Jamir). In terms of programming approach, the children who participated in our study could be divided into three main groups:

- **The coders**. These were the students who were interested in the coding experience and who could spend hours figuring out which blocks and methods they needed to make a character move in a specific way. Most of them had some sort of prior experience with coding and were more interested in designing and building games and animations. These were also the participants who preferred to use pre-trained AI extensions and focus on the code while building their own unique new projects. They loved the fact that the new Cognimates extensions would allow them to extend the type of projects they already did in Scratch but they preferred not to spend time training or testing their own AI models.

- **The trainers**. These students were usually the ones who were initially most focused on the entertainment side of the interaction with the agents. They loved to ask for music and pictures, and interrupt the device with new questions all the time. When they were doing the starter projects from the learning guides, they would spend a long time making things talk and mimic conversations they would have with their friends, or just test the vision extensions by showing all sort of different objects in the camera. Most of these children were not particularly interested in how the extensions or the agents work. They just wanted to quickly see what they could do and test how much they could drill their reactions. For most of the "trainer" kids, they understood aha moments only came when they saw they could make the interaction much more fun when they would teach the computer or the robots to recognize specific messages or images. They preferred spending a lot of time in training and testing their own models (see Alex's example with the cups and cars) but weren't really interested in integrating the models in a coding project. As a design take-away for the "trainer" kids, it would be best to start directly with fun demos of what the agent could recognize and allow them to only add one example at a time that would have a big effect on the way the agent reacts (e.g. use a picture or a phrase that would offset the training set). This would allow for them to sustain attention and engagement and build on that experience because it is immediate enough.

- **The agent companions**. The agent companions were for most part the students who would absolutely fall in love with one of the robots and would only want to spend time interacting and programming that robot. In the case of this school, the affection was especially common with Cozmo robot and would occurred both among the younger and older groups (see the stories of Larry and Sonia). The "companions" would very much understand and acknowledge that the robot's expressions were not real and that it was programmed at the same time they could not resist further exploring the social affordances of the embodied agent. I believe such relationship and interaction can be explored in very useful ways for AI learning as it would bring in kids who are not necessarily fascinated by coding but care a lot about social interactions with a smart toy or a robot and want to explore different ways to engage and modify its behavior.

During the entire study, the children's behavior, language and learning outcomes were recorded and then analyzed. The goal of this data analytic approach was to try to enable children to have as much as possible a natural interaction, both with their peers and with the researchers who acted more as facilitators in their learning process. We also observed that the children had a very limited attentions and patience for filling questionnaires; as a result we decided to video record everything and post analyzed the recordings.

We analyzed the video recording based on existing coding schemes for interaction with technology (PDT framework, [8]) and cognitive and social skills ([32]). We also added a series of new variables specific to our study (time spent coding, change in AI perception). The main goal of this analysis was to determine which of these factors has the biggest influence in the way children change their AI perception and understanding.

In the video coding scheme, a score from zero to five was assigned for each of these components (5 - Always,4 - Often,3 - Sometimes,2 - Almost Never,1 - Never, 0 - Not Observable) and a total score was calculated and compared for each of the main coding categories: communication, cognitive and social skills, collaboration, presenting the work, time spent coding (details about the coding scheme can be found in Annex, see a.2). As seen in Fig. 71, children communicated with each other a lot (maximum score for communication), treated the materials and equipment with respect (maximum score for conduct). They spent 73% of the time coding and 70% of the sessions were collaborative. They expressed cognitive and social scaffolding 60% of the time and presented and demonstrated their work only 34% of the time.

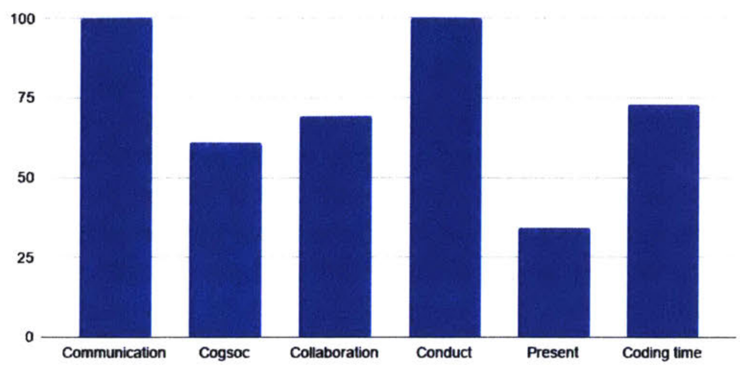


Figure 71: Distribution of skills used by children

Importance of interaction and conversations with their peers We also specifically looked at what type of collaboration([24]) or conversations([40, 71])the children would engage in. As seen in Fig.??, children would engage primarily in exploratory conversations (50%)and cumulative conversations (40%).

During the cumulative conversations, the students would build positively but uncritically on what was said. The flow of the conversation in these situations was characterized primarily by repetitions, confirmations and elaborations.

The participants would engage more critically but constructively with each other's ideas during the exploratory conversations, offering justifications and alternative hypotheses. Children's reasoning was more visible in these kind of discussions.

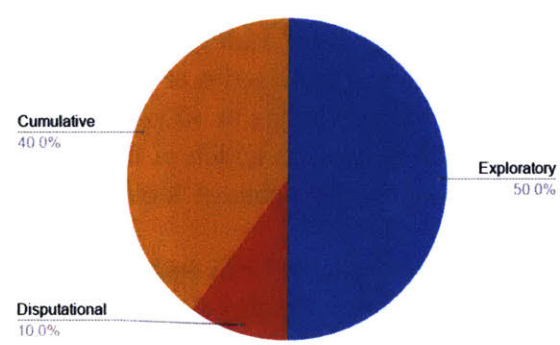


Figure 72: Types of conversations

The predominant way in which children collaborated was by creating coalitions (60%). Often they would form and stick to pairs when programming, and share ideas and resources from time to time. This appraoch was particularly common for the "coders". Most of the "trainer" and "robot fan" kids would mostly coordinate (20%) and mostly share information. Some of the most dedicated "coders" would also manifest collaboration as one system(20%), based on mutual trust and consensus.

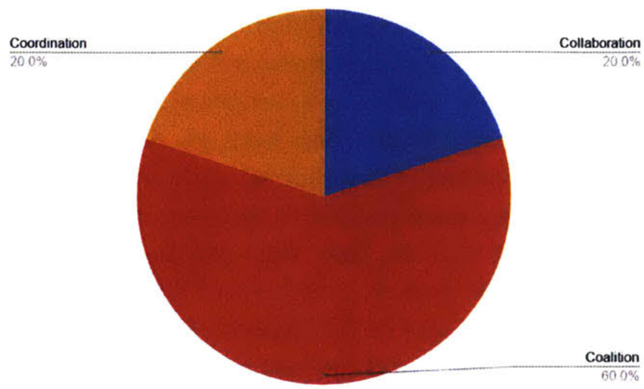


Figure 73: Types of collaboration

6.9 REFLECTION AND INSIGHTS

Almost all of the participants needed more scaffolding for each activity, even if they programmed with Scratch before. Consequently we decided to simplify our activity guides, introduce only one Cognimates extension at a time and focus an activity either on training and testing and AI model that the children could build or on coding projects that use pre-trained AI models or models they had trained before. For most of the children, it was too complex to train a model and use it in a coding project all in one session.

In the first programming sessions we also tried to use our coding missions (described in chapter 1)to help children build specific projects. So the computer would talk and tell them what blocks to use and would react if they used the right or wrong block providing further feedback. The children did not like the missions even if we changed the voice, length or type of projects. They would quickly get annoyed when they didn't understand what the computer said or when they could not go back or do something entirely different. While teachers and parents really like the missions because it helps them learn how to code a program step by step in the case of the children we decided to drop this activity as they very much preferred to explore and learn by themselves and and by collaborating with their peers without such immediate guidance. In future iterations of this feature I think it is important to make the mission mode optional so children can opt-in and out of it during their coding project.

6.10 DISCUSSION : AI EDUCATION IN PUBLIC SCHOOLS

Most of the children who participated in the study, both younger and older ones, had heard about AI and smart robots before, either from popular culture with references to movies like "Her", "Ex-Machina", "Blade Runner, "Big Hero 6" or from the news (many children knew about Alexa and Sophia the robot from the news). Some of the study participants said they had friends who have an Alexa at home but none of them have experienced interacting with these devices first-hand before. Overall, they were excited to discover how these "smart" devices work, what they can do, how they can be controlled. Interacting with the devices in groups was helpful for their learning as the children would scaffold and build on each others' questions or actions. They would also debate and discuss more how an agent might respond or behave in a specific way.

It is worth noting that learning through peer-interaction was particularly important as most of these students were initially fairly apprehensive of outsiders, especially if the outsiders were perceived as belonging to a different SES group. In the first sessions they also described the agents as technologies for "rich people" and most of the younger participants were extremely disappointed that they could not take the robots home. In this context, initially we tried to leverage and put forward the knowledge and approach of the older, more experience children and allow all participants to switch or skip tasks whenever they wanted so they feel in control.

Earning their trust, breaking through the barriers of displayed attitude and getting them to want to think and focus more was a slow process and it could be done almost only by going to the school nearly every day for a month. I was extremely touched by how much they managed to progress in their coding and understanding of AI training and technology, even if many of them were starting from scratch or were struggling with other disciplines in school.

We cannot design learning tools and activities for public schools with low SES families without taking into account the complexity of the children's environment, both at home and at school. In the case of this school, the director of the after-school program would host multitude of external programs and organizations that produce a very rich and diverse schedule of activities for children. In practice though, what that meant was that children would constantly get moved from one activity another, with no rooms for some activities (our research team had to compete and wait for other organizations or use a hallway). The after-school staff was overworked and stressed (all the staffers were replaced during our study there) and therefore would not always treat the children in the most caring and reasonable way. This is a cautionary tale for over-optimizing children's schedule and overwhelming both the children and the people who are supposed to help facilitate the program.

The other big challenge we encountered in this school was the fact that boys received preferential treatment in accessing our study workshops (which explains the limited number of girls that participated in the study). Girls and boys were segregated for activities, which did not contribute to having a constructive integration of genders in our sessions at this school. Moreover the director of the after-school program decided that the activities were more appropriated for older students(8 - 14 years old), despite my numerous inquiries about continuing to work also with the initial group of younger students from the pilot study (6-7 years old) as they were much more open to engage in more exploratory and reflective conversations. When it comes

Figure 74: Kiara (8 years old) programing on Cognimates next to her dad

to parent, we also had to do a lot of work to explain our research and earning their trust. Initially, most of the parents would come to the study site at random times to pick-up their children even if they were in the middle of finishing a project (in contrast to higher SES schools where parents always waited for their children). As most of the parents spoke limited English, I had to bring some of them in to the space and explain in Spanish what the children were doing, how they could continue the activities at home for free. Once I had their attention and interest, I would even try to make them participate by giving them a tablet, with which they could hands-on try the Cognimates projects. We had dads who became interested in coding through using Cognimates, and for several times they attended our sessions, as in the case with Kiara's dad 74. In that scenario, engaging Kiara's dad appeared to be crucial, because she would normally get very anxious every time the dad came to pick her up; but once he got into exploring the platform himself, she was able to focus on the task at hand much more.

Despite all the logistical and cultural challenges, I believe our students in this school pushed themselves and tried as much as they

Figure 75: Group picture with students in the last day of the study

could to learn something new. They persevered and become better at understanding and controlling new technologies. They understood why the activities were important. I also observed how most of students who participated regularly in the sessions pushed themselves outside of their comfort zone: as in the case of Jose who couldn't read, or Jamir who had to retrain his model and help his peers, Sonia who sometimes had to stick to her ground in a male-dominated environment, or Alex who didn't want to actually program or train anything initially. These students showed that they wanted to achieve something and were able to build on each others' strengths. And they showed us how that "human intelligence that is coded in the machine" (as they described it) comes to be.

7 AI EDUCATION IN SHADY HILL PRIVATE SCHOOL

"I was surprised you teach people my age this. When my dad was young he bought a car and fix it, today we learn about these AI technologies" - Nick, 7 years old

Figure 76: Shady Hill School students in the first session

The second long term study took place in the Cambridge Shady Hill School (SHS) from mid April to end of May 2018. Sessions of 1.5h were run biweekly as part of the after-school program hosted in the school maker-space. This school is a private school, with excellent facilities, technology equipment, access, and teaching mainly children from higher SES families. In this study we had a total of 16 participants (ages 6-10 years old) 10 boys and 6 girls that participated regularly in all the sessions. Out of all the participants 10 participants were younger children (6 - 9 years old) and 6 participants were older children(9 - 11 years old).

7.1 PROTOCOL

This study comprised of three phases: 1) initial encounters with agents and perception, 2) programming and training AI, and 3) post-activity perception test. The initial encounter with agents phase was used to gather interaction and perception data, the programming and training phase allowed participants to better understand how these technologies work-by-doing, and the final post-test activity recorded how

Study Phases	Participants	Structure
Initial encounters with Smart Agents 1 Session	16 participants (10 boys and 6 girls) Ages: 6-7 years old -1 ch. (1 boy) 7 - 9 years old - 9 ch. (5 boys and 4 girls) 9 - 11 years old - 6 ch. (4 boys and 2 girls)	1. Interact with 3 different agents(Alexa, Cozmo, Jibo) 2. Program the agents via their coding apps 3.Ask questions about perception of the agents
Programming and training phase 4 Sessions	16 participants 10 boys and 6 girls) Ages: 6-7 years old -1 ch. (1 boy) 7 - 9 years old - 9 ch. (5 boys and 4 girls) 9 - 11 years old - 6 ch. (4 boys and 2 girls)	1. Discover and test starter ai coding projects 2. Complete study learning guides 3. Create their new projects and AI training models
Post-test perception 1 Session	4 participants (3 boys and 1 girl) Ages: 6-7 years old -1ch. (1 boy) 7 - 9 years old - 2 ch. (1 boy and 1 girl) 9 - 11 years old - 1 ch. (1 boy)	1. Ask questions about perception of the agents 2. Conduct interviews to asses children grasp of AI concepts

Table 7: Protocol Shady Hill Private School study

their perceptions of AI changed from the first encounter phase. Because the school staff, children and their parents expressed interest to continue to use the AI education resources shared with them, I decided to go back a month later and see if an how they continued their programming with AI as well as what are their later reflections and insights about the study. I also interviewed a parent and the school administrator for after-school activities who helped us organize and run the study. The names of children used in describing the results, or paraphrasing quotes, were modified to protect children's identity. I ran all the sessions with one of my undergrad interns, Sarah T. Vu, who received the appropriate IRB training and approval. The team of researchers was consistent during all the study sessions.

Figure 77: Children interacting with Jibo and Alexa in the first study session

7.1.1 *Phase 1: Initial Encounters with Agents and Perception of AI Test*

Most of the participants had seen the agents before or had some of them at home. They were fluent in the interaction and wanted to jump into programming in the first session. In the beginning, children didn't want to collaborate as much and were especially debated over who should control the robots. When interacting with Alexa, children often built on each other's questions and spent a long time showing each other tips and tricks in interacting with the device (e.g., making it beatbox, sing a song, tell jokes or riddles).

- Nick: "Alexa, show me a picture of Dunkin Donuts." (repeated)
- Laya: "Alexa, show me a picture of Dunkin Donuts."
- Both: *Laughing*
- Nick: "Alexa, show me a picture of a wedding."
- Nick: "Alexa, does everything you say really get texted to someone? Everything she says gets texted to someone. "

Some of the children try to get Jibo to answer the same questions and were comparing the answers. They also asked the agents about other agents and try to be mischievous in the interaction. Chad, 10

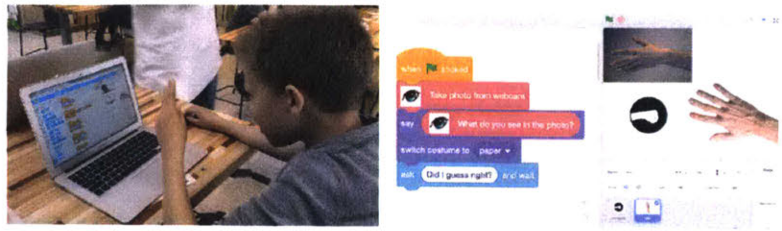


Figure 78: Example of student testing their Rock Paper Scissors game at Shady Hill School (program code on the right)

years old asked: "Alexa, do you have a crush on Google?" After he saw the answer was not amusing enough, he decided to program Alexa with the Cognimates extension: "I'm trying to figure out how to make it say 'I am potato', or, or, I want to say 'Are you a potato?' then it will say 'yes'".

During the initial perception questions, all the children described the agents as friendly and said that the agents like and care about them. They expressed mixed opinions on whether each agent is smarter than them, or if they will tell the truth. The robots were described as more truthful overall, and children justified that choice by saying "robots are supposed to be programmed to tell the truth".

The children asked Alexa and Jibo complicated Math questions to test their smarts. The participants who said the agents are not smarter than them justified it by saying that the agent cannot move and still needs a person to help it move (in the case of Alexa and Jibo): "Not smarter, not smarter. He can't even move an inch without a human helping", Nick, 8 years old. One 7 year old girl said that the agents are as smart as the people who programmed them: " I think it's smarter, but a person created it – so it's as smart as the person but programmed to be smarter".

Children often reference their use of the agents at home (especially in the case of Alexa) when describing how they feel about it, why they think the device understands them (or not), or if it will remember them (or not). All of the children who saw that Cozmo and Jibo can take pictures of them said that the robots will remember them. The majority of children said Alexa, in return, will not remember them. Jibo and Cozmo were described both as animals or something in between a pet and a person. All children described Alexa as a person because it can talk "like humans do".

7.1.2 *Phase 2: Programming and Training AI*

The older children at SHS were quite experienced with coding and were fluent in using the Cognimates block language straight away. Most of them started to help younger children who had less experience with Scratch. Most of the participants went through the starter learning activities in the first session. After, they started to explore all other Cognimates starter projects. By the second programming session they chose make their own projects. There were two exceptions: one boy who was 6 years old preferred to only play with Cozmo and program it on the phone app using Anki's commercial coding app (See Fig. 55). The other exception was Cody, a 10 years old student, who was a more experience coder and preferred to spend most of his time building specific games, scripting sprites animation on screen. Cody really enjoyed also playing pre-coded games like Rock Paper Scissors in Cognimates, or Circuit Saver game for Jibo, but thought they were too complex to program them from the start – and wasn't interested in spending time to train a new vision model for the game. In his case, just like in the case of the older participants in ECSC public school in Somerville, we see the challenge of a mismatch between older children's expectations in terms of interaction and their own ability to modify or create a game that they consider worth playing. The most popular starter projects (see **??**) are the *Jellyfish game* (the most well liked), where a jellyfish floats only if you tell it happy messages (using Speech and Sentiment analysis extensions), the *Good boy* program where a dog reacts with sounds and animations to how you talk to it (using Speech and IBM Text classifier extensions). Very often children wanted to modify the projects to make both the characters more expressive and to add new types of messages the characters could react to (See Fig. 79).

Figure 79: Examples of new animations children made to make the dog sprite look angry or drooling

SHS participants liked very much to play with the IoT extensions as well. They made programs to control a bubble machine to respond to their voice commands, or they connected the Alexa extension to control and trigger the bubble machine (see Fig.80).

Starting from the second session of the programming and training phase, the students started to collaborate much more – especially while training new models. They spent a long time selecting pictures

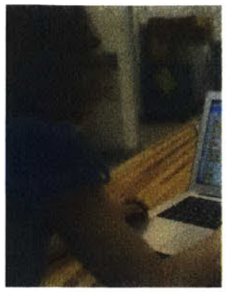


Figure 80: Students programming Alexa and a bubble machine on Cognimates

together to train new models to recognize trains, dogs, and Kirby cartoons. They also came up with all sorts of fun strategies to confuse and test each classifier model by giving it examples of dogs or Kirbies wearing sunglasses. Sometimes children were disappointed they couldn't find all the edge cases example images online that they wanted to use (e.g., "sad Kirby with sunglasses"). Nick, an 8 year old boy, described this part of the study as "hard fun" (without knowing that this is also how Seymour Papert liked to describe Logo programming): "The parts that was hard was choosing the photos you really wanted, and then putting them all together and waiting for it to learn how to do it. It was hard but fun".

7.1.3 *Phase 3: Post-test Activity and Questionnaire*

We only had four SHS participants (3 boys and 1 girl) for the Post-test questionnaire activity in the study since most of the children wanted to continue to spend as much time as possible programming and playing with the agents (even in the last session). The school reinforced a culture where children are allowed to choose and switch after-school activities freely, and they asked us to give the children as much freedom as possible during the sessions. So, we did not insist that the children partake in any of the questionnaires if they refused.

7.1.4 *1-month Followup*

A month after the end of the study, we went back to interview the students, parents and teachers at SHS to see how they might reflect on their experience and what they learned. We interviewed four younger children (1 boy and 3 girls) and two older children (2 boys). We also interviewed one father and the after-school coordinator. The children remembered us and were able to describe in detail what they learned and what programs they built: "I taught a computer face recognition, colors, numbers, colors and animals and pictures... so then it would work, so it would work, so someone would help... so it would be better", Mia 7 years old.

Some students said their favorite part was to teach the machine.

> "Teaching the computer really felt good (why?) Because I like, liked it.. and it was really fun... and it was really good because I liked when it got to, we taught that stuff, so that I did it.", Mia, 7 years old.

All the students recognized why it is important for them to learn these skills.

> "I was surprised that you taught people my age how that complicated stuff works, but I thought it was really cool. When my dad was young, he bought a car and took it apart to see how it worked. So yeah. It's surprising that you teach people that young how these things that grown-ups mostly program how it works", Nick 8 years old.

The interviews highlights are summarized in this 1 minute video: http://bit.ly/shaddy_cognimates/.

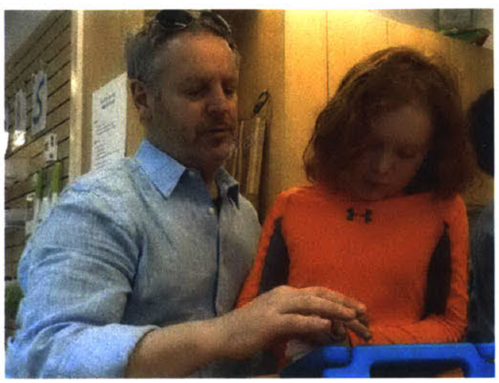


Figure 81: Dad and son programming together

7.2 QUANTITATIVE ANALYSIS

> "Because he's a robot, so he's probably going to have lots of things programmed into him that he knows and he doesn't have to remember them. Humans have to remember the stuff, but robots don't.", Liam 7 years old.

The following table describes the demographics distribution of children who completed all the phases of the study and who's data we analyzed in this section 8.

7.2.0.1 *Pre/Post Perception of AI Questions*

We ran Shapiro-Wilk (S-W) test to check for normality (p>0.05) and Levene's test to check for equal variance (p>0.05), and hence chose to

Students Young 3 Older 1 Girls 1 Boys 3	count	4.00
	mean	7.50
	std	1.56
	min	6.00
	25%	6.75
	50%	7.00
	75%	7.75
	max	10.00

Table 8: Table of Participants Age and Gender Distribution in Shady School's final perception study

perform a sample t-test for proportions between pre- and post- questionnaire responses. Participants changed their answers from "yes" to "no" significantly when asked if the agents will remember them ($p = 0.0062$ for "no" pre-to-post, $p = 0.00182$ for "yes" pre-to-post). When describing if the agent understands them, several children changed their answers from "yes" to "no" ($p = 0.19672$ for "yes" pre-to-post) (see Fig.83).

Not all of the perception questionnaire questions could be addressed pre- and post the coding study phase. But when describing if the agent is friendly at the end of the study, we saw more children replying "maybe" and "no" than "yes" (see Fig.84). They would say that the agent behaves in a friendly manner but it was programmed to do so:

> "Because, he looks like he has feelings, but he might not. You can make him, like, sad, happy, surprised, bored", Liam 7 years old.

Overall, we saw the majority of children changing their answers to the perception questions pre- and post the coding and training sessions (see Fig.85). Children became more skeptical of the agents human like abilities, like remembering and understanding them (see Fig. 83. The shifts numbers were negative when more children changed their answers to a question than the children who kept the same answer. The way participants explained their reasoning and influenced each other will be discussed in the next qualitative analysis section.

Children referenced programability as one of the main arguments for their change of opinion (as coded in the video recordings of the perception questionnaires). The children changed their answers from "yes" to "no", when asked if the agent will remember them referenced more complex explanations referring to the agent "memory disk" and the fact that someone programmed the agent to take pictures and record their voices but those features could be reversed. Children's communication and cognitive scaffolding skills helped them revise their opinions and internalize explanations and concepts presented

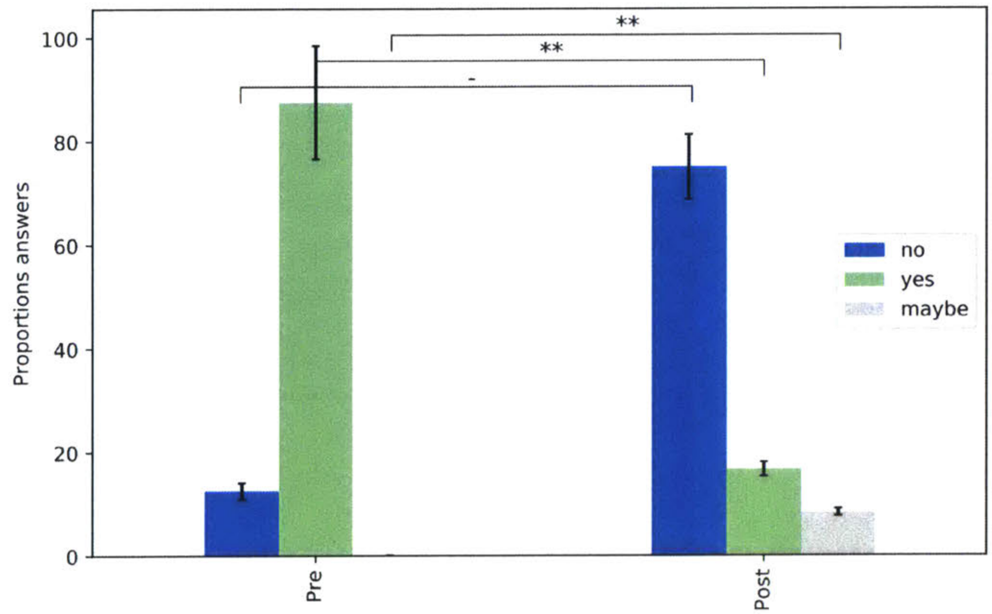


Figure 82: "Will the agent remember you?" answers Pre and Post at Shady Hill School, * p<0.05, ** p<0.01

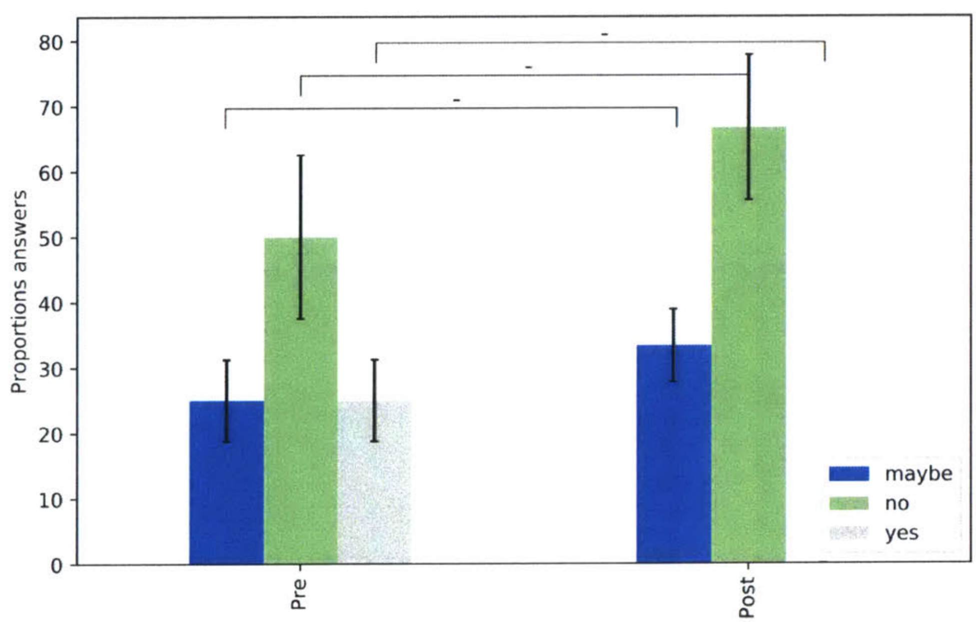


Figure 83: "Does the agent understand you?" answers Pre and Post at Shady Hill School

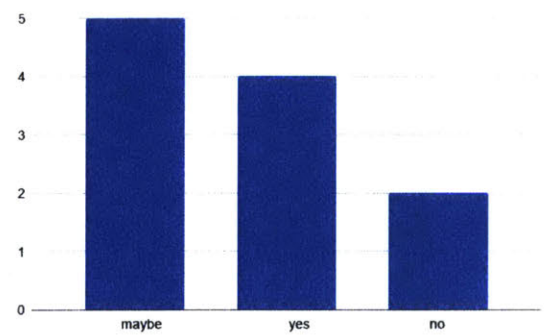


Figure 84: "Is the agent friendly?" answers Post coding, y axis = N answers

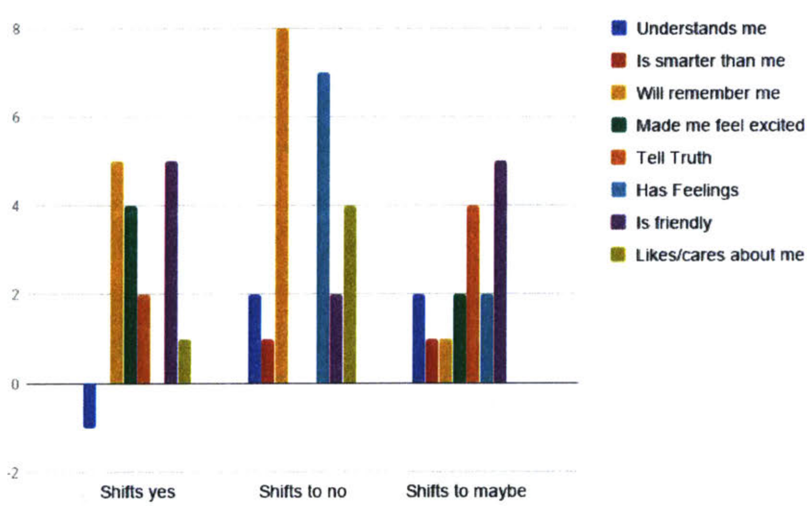


Figure 85: "Answers shifts for each perception question at Shady Hill School

by their peers. From the video recordings, we observe that communication and collaboration played a more important role in helping participants advance in their AI understanding, than time spent coding or prior experience did.

7.2.0.2 *Sentiment Analysis of Children's Conversations*

We transcribed of all recorded conversations in this study. We found he average AFFIN sentiment score was 117.6 and the average comparative was 0.054 – showing that the overall conversations were mostly neutral, just like in the case of ECSC Public School. Overall, Shandy Hill children used a more technical language when compared with students at the previous location. For instance, words like "program" were mentioned 34 times and "computer" 25 times. In order to better illustrate these results I created a series of word clouds 86.

Figure 86: Word clouds generated from the transcripts of children conversations during the study (interaction and coding time): Positive terms, Negative terms

The most frequently mentioned agent in children's conversations was Jibo with 52 mentions, followed by Alexa with 31 utterances, and Cozmo with 29. It is worth mentioning the school has received one Jibo robot as a donation during the study and several of the study participants had played with this robot before. This shows that children would talk more about an agent if they have been familiarized with it before. By talking more about an agent, and discussing its abilities, youngsters are able to debate and deepen their understanding of the agent's inner workings.

7.3 QUALITATIVE ANALYSIS

> "Because you have to teach computers. Like, computers are like us, when we're babies, we don't know anything, but then as we get older, someone has to teach us everything ", Sonia, 7 years old.

The following section describes the observed changes in the way that children described and perceived the agents, both before and after the coding and training session. I also discuss their understanding of AI concepts and give examples of explanations and definitions they used.

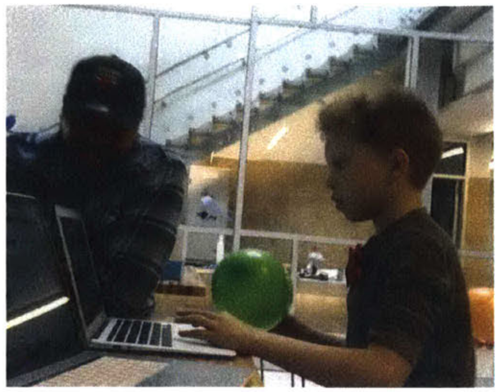


Figure 87: Student making a program that could recognize his green balloon using color detection

7.3.0.1 *Changes in Perception of AI*

When talking about agent's smarts and truthfulness, most of the children would choose "middle" in the post survey. It was sufficient for one child to use programmability as an argument for all the other children to change their opinions as illustrated in the following conversation between the author and Liam, who is 7 years old:

- "So do you think Cozmo will always tell the truth?"
- *All participants choose always tell the truth* "Why?"
- "Because he is a robot."
- "Do robots always tell the truth?"
- "Well in the middle, because if you program them not to tell the truth."
- *All other kids change to the middle option*

7.3.0.2 *Coding and training strategies*

Children really started to work together and collaborate when they began to train their own models. They understood that for a model to perform well and give accurate predictions when classifying a picture or some text they needed many examples. So, children started to divide roles in gathering all the data they needed and spent a long time debating how to test and confuse the models they created (e.g., add pictures of dogs with sunglasses and see if they get recognized like a dog or pair of sunglasses – see Fig.88).

When asked why they are giving the computer so many examples of images the children replied:

- Nick:"Because you want the computer to know why you want it to know something."

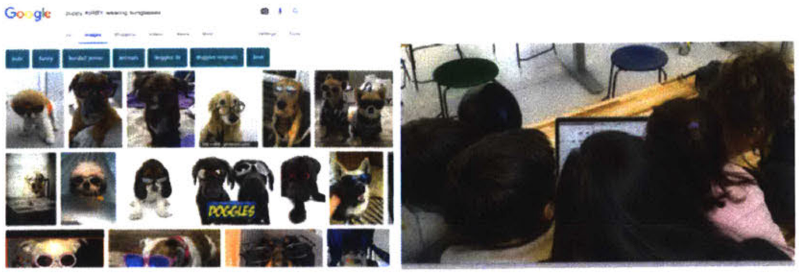


Figure 88: Training a model with puppy and kirby pictures and then trying to confuse it

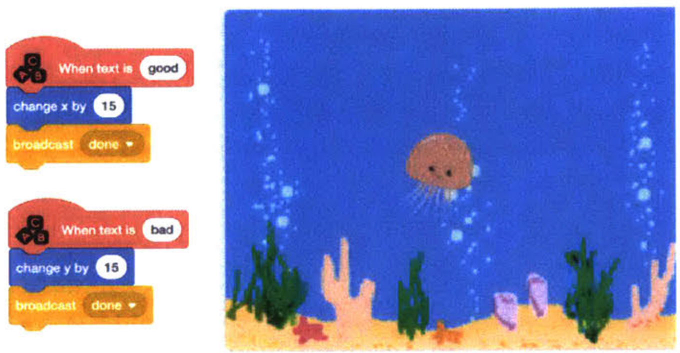


Figure 89: Example Jellyfish program reacting to speech feelings

- Laya: "I have an idea (..) because it's going to learn what those pictures are going to be."
- Researcher: "Do you think computers already know things. or do you think people teach it?"
- Laya and Mia : "People!" (very passionate)
- after Mia realizes: "We taught a computer? Sometimes a computer teaches me!"

The more comfortable children became with the Cognimates platform, they began to help each other more, and exchange tips and tricks for how to get their programs to work. Students also helped each other figure out how to find and use new extensions. They also shared what phrases or images caused a funny effect –and discussed their hypothesis about why something worked or didn't.

Here is an example of interaction between three younger children (Laya and Neo, both 7 years old, with Nick who is 8 years old) and one older child (Chad, 10 years old) when trying to use and modify the Jellyfish starter project.

- Laya: (to Chad as she walks over to him) "What is that? Can I see what it is?" (about Jellyfish project)
- Chad: "Do I download the project?"

- Neo: "Yes, yes, yeah, download the project." (goes over to help Chad)
- Laya: (asks Nick after seeing the researcher help Nick set up) "Can you do it for me?" (Nick goes over to help)
- (Children say positive and negative statements to play the game and make the Jellyfish float)
- Laya: "You are a chicken." (copying Nick's statement from a couple seconds before)
- (Chad is patient with his statements, repeats them over carefully and uses shorter phrases. Nick, in contrast, expresses more fueled statements, and changes statements quickly and makes longer statements. After a while, he copies Chad's strategy)
- Chad: "I think I've encountered a glitch."
- Laya: "Me too."

In this interaction, we can see how children not only help each other when they get stuck (without asking for help from the researchers or other teachers), but also how much they scaffold and build on each other examples (e.g., "You are a chicken.") as well as their process (e.g., making shorter phrases and pauses). We also see a transfer of knowledge and terms from older children to younger children. For instance, Laya understands on the spot what a "glitch" is (a term used by the older child, Chad), and she appropriates the term.

In order to foster these interactions to occur naturally, rich with cognitive and social scaffolding, it is crucial for the learning platform to respect the principles of having a "low floor" with an easy and accessible programming language that anyone can easily pick-up and an intuitive interface (e.g., blocks-based), with "wide walls" that allows for the elements of the platform (e.g., blocks, sprites and extensions) to be combined in numerous and diverse ways, and a "high ceiling" that enables more advanced users to build more complicated features (e.g., such as custom methods, lists, and even custom extensions that they can train themselves). These principles were first proposed by Mitchel Resnick for the design of the Scratch platform [53]. I used and adapted them in the context of Cognimates, specifically for AI education. The specific interaction above illustrates and validates that Cognimates is a platform that can successfully engage children of different ages, and allow them to collaborate and scaffold starting from the same project.

Going back to the Jellyfish project when the children were asked how they think the program works they said:

- Chad: "I saw a bit of the code. I think it works because it says, um, when you hear good, or happy speech, then, go up" ...

"and when it hears bad, er um, mean - I don't know the word - speech, it just says go down. Then it says when you're out of bounds, make beeping, make, make loud annoying beeping sounds. And when you hit the side, switch directions."

- Researcher: "How does it know if something is good or bad?"
- Laya: "Because, sometimes it says, like, if you want to have like, a sound or something, and then, like, if you wanted to hear what you're saying, and, and then it can hear you what you are saying and then, and then it knows if it's a happy speech or a bad, a happy speech or not a happy speech"
- Nick chimes in: "I think it's because it listens to you, and it knows what's happy because someone taught it, and it knows what's bad because another person taught it."

During the coding and training phase of the study, I saw children reflect on explanations and arguments heard from their peers. It is important to acknowledge that children internalized and appropriated new concepts about AI and machine learning because they heard them from their friends and colleagues – explained in a manner that they could really relate to and in reference to a common experience (like in the example above with the Jellyfish project).

Children explanations of AI concepts By the end of the programming sessions, all the children (except for the youngest, 6 year old participant) were able to identify and explain various AI components and concepts while interacting with different cognitive services or embodied intelligent agents. Their explanations and definitions of AI concepts are summarized in Table.9.

7.4 COLLABORATION

In the case of Shady Hill School, children had a harder time sharing the study equipment in the beginning as compared to East Somerville Community School (ESCS) Public School. As many of the participants reported having an Alexa, Cozmo or Jibo at home, they were very reluctant about sharing the access to the agents initially. The group attitude really changed when we started the coding and training sessions. Even if some of the older participants were fluent in coding with Scratch, many of the Cognimates extensions and features were new and engaging. We say them enjoy exploring how they work with the younger children. The children collaborated the most during the moments where they trained models to recognize pictures and text as they worked together to collect all the training data. After gathering the pictures, they start riffing off each other's ideas for new ways to test their models and to confuse them. This was also a pivotal mo-

Ai Concept	Child explanations
Sentiment detection	Chad 10 years old :"A sentiment is a feeling. So the thing with sentiments is if you get a sentiment of happy now the block already knows after you typed it in it knows that happiness is positive. So if your sprite gets a message that is unhappy it can change to a unhappy sprite."
Supervised learning	Mia, 7 years old explaining how you could teach a computer to play RPS: "Well, you have to code in 'this means rock, this means scissors, this means paper, then it would recognize that as the things (..)the computer gets better as you play the game, cause it's like us. We might not know everything at first, or we might know something but not very well, but if we keep trying, we get better. So does the computer."
Color Detection	Chad: "We're trying to make a computer recognize colors by having pictures and labeling them as colors. So like I put my balloon here and take a picture and label it as green so the computer can recognize green"(why'd you try to make the balloon fill up as much space as possible?) "Because if it's recognizing the color green, there should be as much green as possible, and not brown" (points to brown wood on the side)
Image Recognition	Nick, 8 years old: "So we went on Google and we chose like, 10 photos, and then put them in one category and then you could tell it what it was and then you could test it by tapping on, like, there was like a little box that had one of the photos and you could tap on it, and then it would tell you what it was (..) so if you want to teach it what a telephone is then find pictures of a telephone, like if you said "telephone", but then put pictures of a purse, it would think a purse is a telephone, you're in charge of teaching what it actually is."

Table 9: Children explanations for different AI concepts

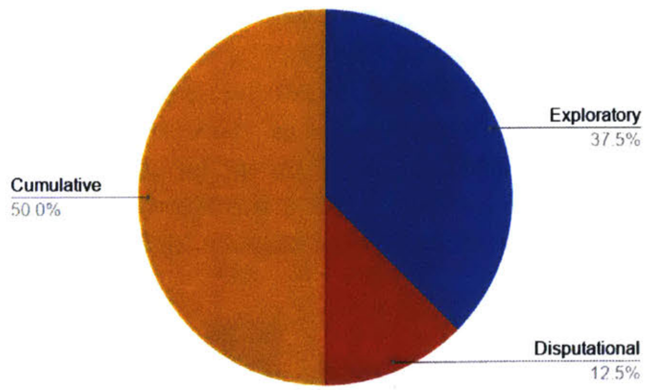


Figure 90: Types of conversations at Shady Hill School

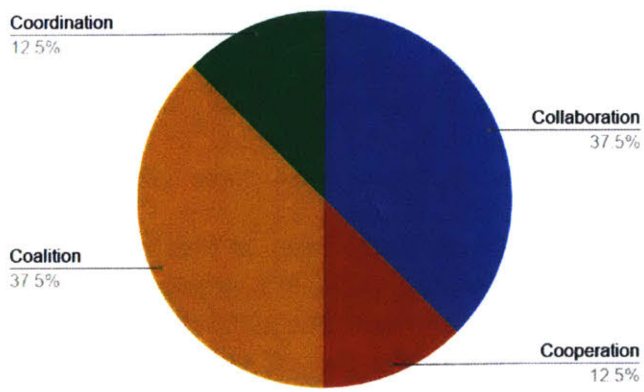


Figure 91: Types of collaboration at Shady Hill School

ment in terms of their own understanding for how the agents can recognize faces or voices.

During the different phases of the study, children engaged primarily in cumulative conversations (50%) and exploratory conversations (40%) (see Fig.90). There were 10% less exploratory conversations than in ECSC school, and 2.5% more disputational ones.

The ways in which children collaborated were distributed primarily between collaboration and coalition (both 37.5%)(see Fig.91). Compared to the previous public school, children would collaborate more in groups during training sessions (as opposed to pairs). There were also more cases of children acting as one team (37.5% vs 20% Collaboration) – not only building on each other ideas, but also debating and changing each other opinions in constructive ways. At Shady Hill school, there was also more collaboration and conversations across genders.

Children's behavior and language were recorded, transcribed, and analyzed from video. Based on our coding scheme, a score from 0 to 5 was assigned for each of these components (5 = Always, 4 = Often , 3 = Sometimes, 2 = Almost Never, 1 = Never, 0 = Not Observable).

A total score was calculated and compared for each of the main coding categories: Communication, Cognitive and Social skills, Collaboration, Time spent coding (details about the coding scheme can be found in Annex, see a.2). As seen in Fig. 92, there was a high score for most of the coding categories (> 75%), except for coding time (30%). The main reason is that children spent a significant amount of time training new models which we did not score as "coding".

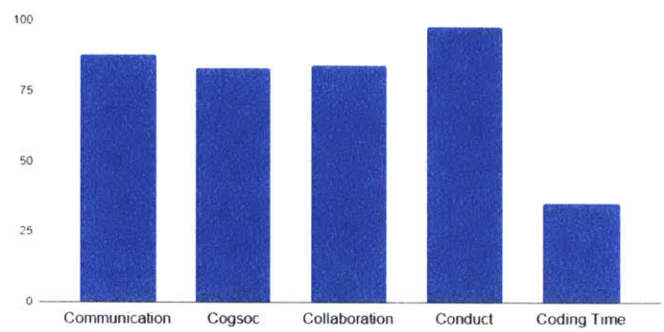


Figure 92: Distribution of skills used by children

Compared to ECSC school, the children at Shady Hill had higher cognitive and social scaffolding skills, but slightly lower communication scores. Overall, we saw how the collaboration of the group evolved in significant ways as they moved away from engaging with the agents as a consumer product, and they become more involved and skilled at coding and training such devices.

7.5 REFLECTION AND INSIGHTS

7.5.1 *AI perception changes after coding and training*

The children who had strong opinions and were skeptical about the agent's smarts, truthfulness, and capability to remember them didn't change their opinions pre- and post-coding phases– but they significantly refined their arguments (as captured in Table.9). The demonstrated that they were able to deepen and develop their own understanding of these technologies. The children who initially were not so sure about the agent's nature or their abilities went back and forth in deciding how capable the agents are. However, they would change their answers and became more critical when they realized that all the different features the agents displayed can be programmed. It was interesting to observe that the most important attribute for the agent was intelligence. Once it was redeemed as smart, this would strongly influence children's answers to all other questions – e.g., they would say "A robot can be trusted because it is smart." or "It understands and will remember because he is smart."

Some of the children understood that an AI agent can learn beyond what it is programmed to do, but children also recognized the limitations of the AI agent's learning abilities. As a result, children weren't so sure if they should classify the agents as smarter than them or not. When asked if the computer learns differently than he does, Nick, 8 years old, replied: "Well, I think they learn kind of the same and kind of different. Because when we learn stuff, we can forget it... but then we can look for it in the real world. But, computers almost never forget it. But if they forget it, they can't look for it in the real world."

Travis, a 10 years old, pushed this idea even further when answering the same question in a separate interview. He starts imagining what would happen if the computer learns how to learn: "If the computer knows how to learn, I think it would be easier to make it, um, a robot version of a person. Because it can learn like a person, and then it could probably think like a person, move like a person, and act like a person. And then, someday, someone - a person in your house - could be a robot."

Other children recognized their responsibility and agency over how the devices learn: "I taught it face recognition. I would go like, oh, this is the real face. No this is the real face. No this is the real one, and it would be really mixed up, and it wouldn't know who is who.", Laya, 7 years old.

7.5.2 *Design Considerations and Insights*

In the case of the younger participants (6-9 years old), the different characters (sprites) and starter projects served as an important mediator and analogy for the different AI concepts they were learning about (sentiment analysis, object detection, etc). This persisted over time. In follow up interviews one-month later, children would still reference the different projects and characters. They often referred to them in their explanations: "It had a camera, which went to the keyboard, which is kind of like our brain. And then it was like, 'Oh this is yellow.' It's trying to save this person. Like it transferred the yellow into a lifeboat to save the people, and the people didn't die", Sonia, 7 years old.

In terms of AI teaching and training, one of the highlights for the children was the fact that they can confuse the AI by showing it examples that combine the different things it is trained to recognize (e.g., dog with glasses). The experience of confusing the robot or the computer was primarily attractive for children because it was perceived as fun. But I think they also liked it and referenced it many times later because it would give them a strong sense of agency over what the machine can do. Based on this experience, I think it would be good to develop and integrate a special box of "confusing examples" on the training page of Cognimates, so children are always encouraged to try this.

7.6 AI EDUCATION IN A PRIVATE SCHOOL

Shady Hill School presented all the conditions for a flourishing environment for any kind of learning. The campus had all the required facilities and equipment. The school staff were extremely supportive, and had a "child first" mentality – allowing their students to self-regulate and take more ownership over how they invest their time in the after-school program. Many of the teachers were curious, and they self-initiated in learning more about our study and the tools we used on their own while planning ways to continue to use them in the classroom.

The parents were also extremely involved and supportive of the children. A few parents waited for their children for 30 minutes as their children didn't want to stop the Cognimates activity. A few parents would even regularly join and program with their kids.

The children who participated in the study went beyond the starter projects activities, created many other projects, and trained new models. They also developed a deeper grasp of AI concepts and processes, and were able to explain them to other children and adults.

Why did children at SHS advance further in their AI learning experience compared with the ECSC public school? I think the biggest difference is the attitude of the school staff. Overall the children in this school were given more freedom, were treated as individuals, and this allowed children to take more ownership and responsibility in their own learning process. I think they also had more fun participating because they really wanted to be there of their own accord, and there was no sense of obligation towards the school administration. They clearly had fun engaging with the coding and training sessions – even when they were "hard fun". The parents in this school were also extremely supportive of their children and very involved in the whole study. Some of the parents started to participate in the sessions as well and learned how to program together with their child.

The SHS students progressed at an impressive rate, and they demonstrated how far children of their age can go in understanding and building with AI. They understood the importance of AI in their future – because AI devices are "the cars" of their generation – as one of the students described them.

8

AI EDUCATION AT EMPOW STUDIOS: STEAM ENRICHMENT CENTER

"Do you think that all robots will always tell the truth?"
"Yes,except for the lie detecting." - Jason, 8 years old

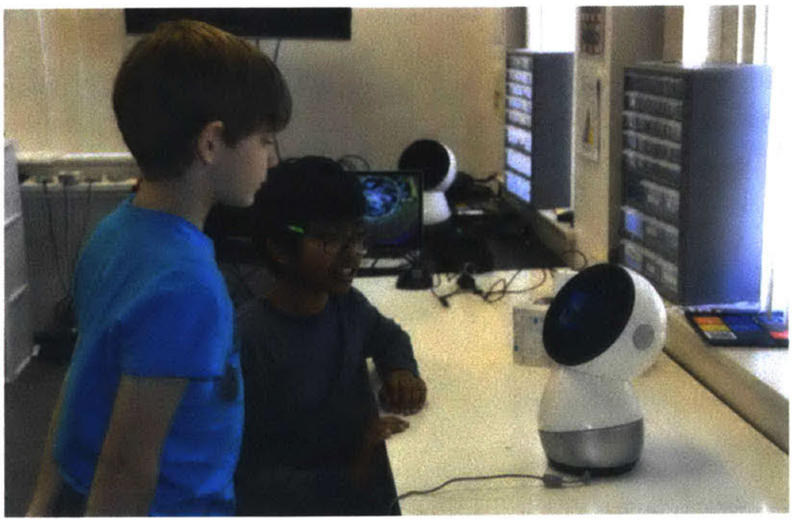


Figure 93: Empow setup

The third long term study took place in the Empow Studios, an after school center offering hands on science, technology, engineering, arts, and math (STEAM) enrichment opportunities in Lexington, Massachusetts. Our study ran from mid-April to the end of May, 2018. Sessions of 1.5h were run biweekly as part of the center workshop offerings, and they were hosted in the center's computer room. This branch of Empow Studio is located in the center of the most affluent part of Lexington. It provides all sorts of robotics and coding classes, has good technology equipment, and a dedicated staff that is highly trained in technology and science education. The children who attend workshops are from medium and higher SES families from area. In this study we had a total of 7 participants (ages 6-10 years old) 5 boys and 2 girls. Out of all the participants, 2 participants were younger children (ages 6 - 9 years old) and 5 participants were older children (ages 9 - 11 years old). Out of the 7 participants only three (2 girls and 1 boy) completed all the sessions of the study.

8.1 PROTOCOL

This study was comprised of three phases: 1) initial encounters with agents and perception (one session), 2) programming and training AI (four sessions), and the 3) post-activity perception test (one session). As in the cases of ECSC and SHS, the initial phase was used to gather interaction and perception of AI data. The programming and training phase aimed to teach children how AI works. The final post-test phase examined how their perceptions of the smart agents may have changed after exposure to the Cognimates activities.

At Empow, we also ran a series of demo sessions for parents and the broader community as part of the Cambridge Science Festival. All the names of children used in describing the results, or paraphrasing quotes, were modified to protect children's identity. I ran all the sessions with one of my undergrad interns, Tammy Qiu, who received the appropriate IRB training and approval. The team of researchers was consistent during all the study sessions.

8.2 PHASE 1: INITIAL ENCOUNTERS WITH AGENTS

Empow Studios already had a Jibo robot, and some of the participants had previously heard of Alexa, and it was their first time interacting with the Cozmo robot. During the first encounter, participants were very excited to play with the agents. Even other children who were not subscribed in the study wanted to participate, and the researchers needed the center's staff assistants to manage their enthusiasm. The seven children who were subscribed in the study were mostly older and took turns in interacting and programming the agents that were placed on different tables. The participants were very good at taking turns and sharing the equipment. They were very interested to program and control the robots. During the initial perception phase, some of children would often repeat the questions to the devices or interact with them, while trying to asses how to respond the questions. Shinani, 11 years old, was very categorical in her arguments against agents being able to have human like characteristics (feelings, to care). But she said the devices are "cute," and she enjoys programming them. The group of older boys, who did the perception questionnaire together, influenced each other's answers quite a bit. One of them announced that he had an Alexa at home and that might bias his answers.

One of the main factors that led them change their opinion was comparing the agent with themselves directly – and not just with a hypothetical person. When asked if Alexa is smarter than them two of the boys said "yes." However, when the third boy said "Well it doesn't know common sense." all the boys changed their answers to "no" saying "Hmm... that's a good point." They also used the movement

Study Phases	Participants	Structure
Initial encounters with Smart Agents 1 Session	7 participants (5 boys and 2 girls) Ages: 7 - 9 years old - 2 ch. (1 boy and 1 girl) 9 - 11 years old - 5 ch. (4 boys and 1 girl)	1. Interact with 3 different agents(Alexa, Cozmo, Jibo) 2. Program the agents via their coding apps 3.Ask questions about perception of the agents
Programming and training phase 4 Sessions	7 participants (5 boys and 2 girls) Ages: 7 - 9 years old - 2 ch. (1 boy and 1 girl) 9 - 11 years old - 5 ch. (4 boys and 1 girl)	1. Discover and test starter ai coding projects 2. Complete study learning guides 3. Create their new projects and AI training models
Post-test perception 1 Session	3 participants (1 boy and 2 girls) Ages: 7 - 9 years old - 2 ch. (1 boy and 1 girl) 9 - 11 years old - 1 ch. (1 girl)	1. Ask questions about perception of the agents 2. Conduct interviews to asses childrens' grasp of AI concepts

Table 10: Table Protocol Study at Empow Center

Figure 94: Children interaction and programming with Agents at Empow Center

argument when justifying some of the agent's abilities: "Alexa will always tell the truth because it physically can't do anything else.", said Teo, 10 years old. Overall, the children agreed that the agents are friendly and saw them mostly as truthful.

8.3 PHASE 2: PROGRAMMING AND TRAINING AI

During this phase, the older boys who thought we were "just doing scratch" decided that they were no longer interested in the coding sessions and stopped coming. We were then assigned a smaller conference room where we continued to work with the remaining three students (2 girls and 1 boy). They continued to participate in all the remaining sessions of the study and worked very well together.

8.4 PHASE 3: POST-TEST ACTIVITY

For the Post-test activity we only had the three remaining participants. The findings of how their perception of AI changed pre- and post-study are analyzed in detail in the next section.

8.5 QUANTITATIVE ANALYSIS

Overall, we saw the majority of children change their answers to the AI perception questions post the coding and training sessions (see Fig.98). Children became more skeptical of the agent's ability to be smarter, to remember them, or to have feelings. More children said that the agent might be able to understand them and explained that they could perhaps make it understand them better through code.

The following table describes the demographics distribution of children who completed all the phases of the study. We analyze their data in this section 11.

Students 7 Young 2 Older 5 Girls 2 Boys 5	count	7.00
	mean	9.00
	std	1.50
	min	8.00
	25%	8.00
	50%	8.00
	75%	11.00
	max	11.00

Table 11: Table of Participants Age and Gender Distribution in Empow Steam Education Center

8.5.0.1 *Perception of AI Questionnaire*

We ran Shapiro-Wilk (S-W) test to check for normality ($p>0.05$) and Levene's test to check for equal variance ($p>0.05$), and hence chose to perform a sample t-test for proportions between pre- and post- questionnaire responses. Our sample t-test results showed that students changed their answers from "yes" to "no" significantly when asked if the agents are smarter than they are ($p = 0.0184$ for "no" pre-to-post). In the post questionnaire there were no more "maybe" answers to this question ($p = 0.0085$ for "maybe" pre-to-post). None of the children said the agents would remember them in the post survey ($p = 0.0429$ for "yes" answer changes). All the children that initially said that the agents like and care about them changed their answers to "no" and "maybe" at the end ($p = 0.0088$ for "yes" pre-to-post, $p = 0.05$ for "no" pre-to-post, $p = 0.09$ for "maybe" pre-to-post). See Fig.97.

In comparison to the initial AI perception session, the children no longer addressed the questions to the agents. Rather, the children were more categorical in their answers. Many of them switching their answers from "maybe" to "yes" or "no" (see Fig.98). The only question that had a significant increase in the number of "maybe" answers, was the "Understands me" question because children weren't sure if they could make the agent understand them better through coding.

8.6 QUALITATIVE ANALYSIS

In the following section, I discuss how children explain how they perceive the agents, what their most common coding and training strategies were, and how working together influenced their process.

8.6.0.1 *Perception of AI: Changes Pre/Post*

> "Will remember me or not remember me? Hmm, if you use a different setting it won't" - Privan, 11 years old.

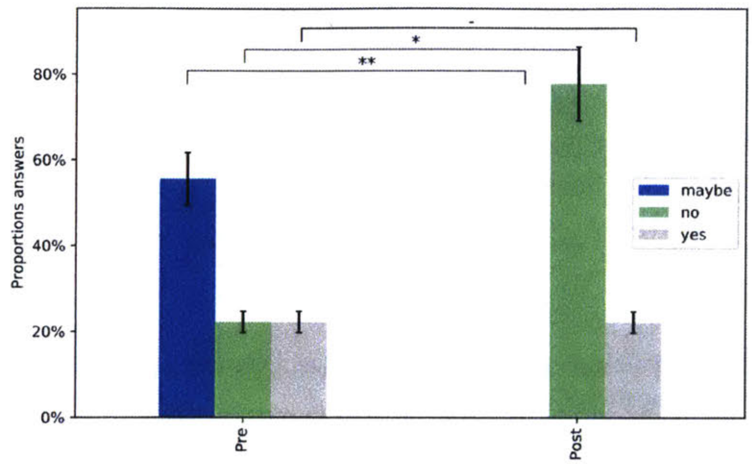


Figure 95: "Is the agent smarter than you?" answers Pre and Post at Empow Center, * p<0.05, ** p<0.01

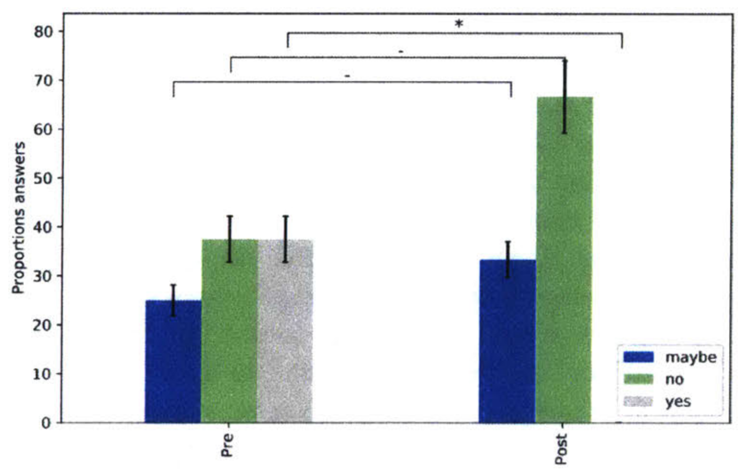


Figure 96: "Will the agent remember you?" answers Pre and Post at Empow Center,* p<0.05, ** p<0.01

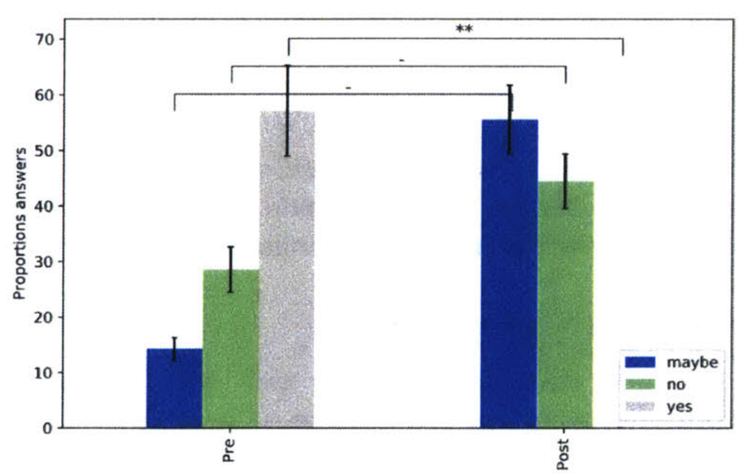


Figure 97: "Does the agent like and care about you?" answers Pre and Post at Empow Center, * p<0.05, ** p<0.01

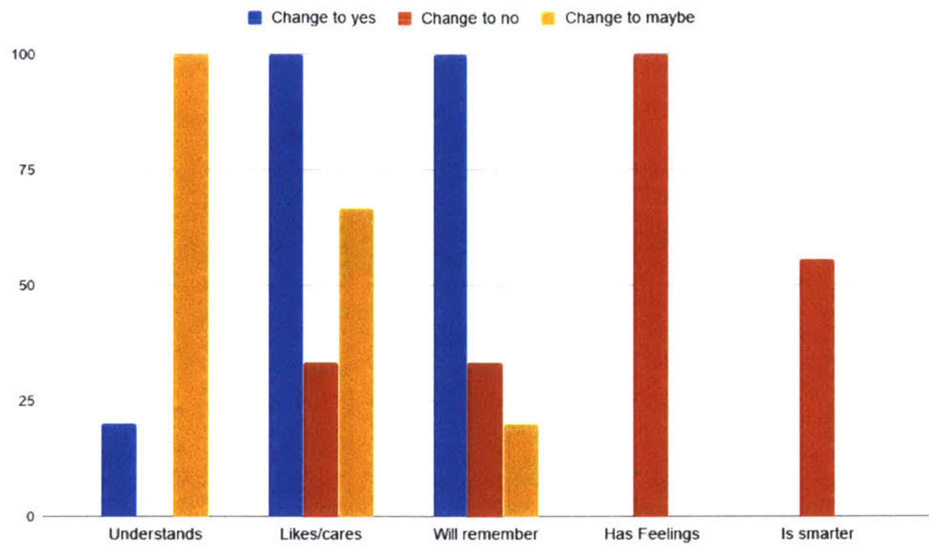


Figure 98: "Answers shifts for each perception question at Empow Center

In the pre- phase, children addressed many of the perception questions to the agents themselves: "Hey Jibo, how smart are you?" When they saw that the answers the agents provided were non-conclusive (e.g., "I try my best."), children came up with all sorts of questions that would allow them to asses the true nature of the agent. For example they asked simple questions like "Hey Alexa, how are you?" to see how friendly the device behaved and if it would reply like a person. When trying to determine the smarts of the devices, the students usually asked them difficult questions that the children couldn't answer themselves (e.g., often math questions):

- "Alexa, what's 2031 times 200?", asks Jason, 8 years old
- "406200.", replies Alexa
- (Jason has an awestruck expression)
- "How do you think she can do that?", asks the researcher
- "I don't know...maybe she has some sort of calculator."

Shinani, 11 years old, is pretty confident from the beginning that none of the agents are smarter than she is. She says that Alexa, however, is "pretty smart for a robot."

Recall that in the pre-session, when initially asked if the devices would remember them – the children justified their answers by referencing agent features that they observed during the interaction. For instance, the presence of settings in the robot's menu – "if you use a different setting it wont remember me," said Privan, 11 years old. Younger children would justify their answers based on the size of

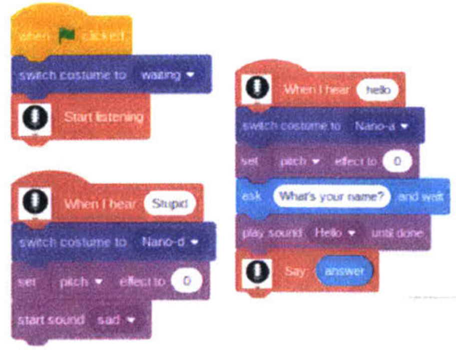


Figure 99: Example Shinani project

the agent. For instance, they would comment that Jibo will remember them but Cozmo will not because "he doesn't have space for a memory bank" – Jason, 8 years old. He would later change both of his answers to the "smart" and "remember" questions as he grew to understand that the "memory bank" could live in "the Cloud" where any agent could connect to it and learn via the Internet.

8.6.0.2 *Coding and Training Strategies*

> "What do you like about playing with these robots?" "You can program them to do other things, or learn how they work, and how the inside coding works" – Shinani, 11 years old.

Shinani, age 1, was a more experience programmer and already programming with Python. In her first project (inspired by the "Smart home" activity), she decided to make a program that replied to her commands, play music, remember her name, and greet her. See Fig.99. After all the children completed the starter activities, they decided to modify the *Clarifai Dinosaur game* to recognize them instead. They started to take many pictures of themselves, and from various angles, so they could train a model with three categories (labels) – one for each one of them. They didn't have time to finish testing their model in this session. So when they got back, they realized their model isn't working as well as they thought it might.

Initially, Jason (the younger boy) said that the model doesn't recognize them "because they are wearing different clothes." Shinani discovered that they were getting predictions for other objects that appear in the picture. So she decided that the problem was that they had too many objects in the frame. They decided to train a new model where they all took pictures in front of a wall with the same background. Their new model worked much better, and they were very happy with the result (see Fig.100).

During the coding and training phase, Cleo (9 years old) and Jason (8 years old), enjoyed playing with the Color and Speech extensions

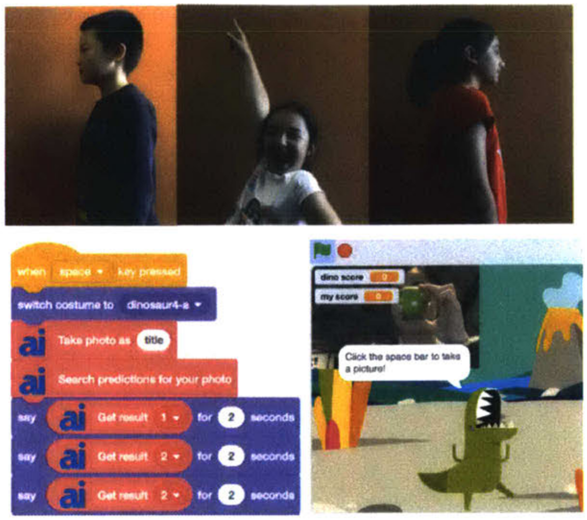


Figure 100: Example modified Dino Game at Empow STEAM Center: top children taking pictures to train model, bottom code example

Figure 101: Child playing with Cognimates during the Cambridge Science Festival demo day

the most (they loved balloons). They also enjoyed programming Jibo with the BeAMaker app. Over time, they became very creative about teaching and testing models to recognize their shoes, drawings, and all sorts of random objects they could find around them. They understood that for the model to recognize drawings, it needed to have examples of drawings in the training set, and not just photos of real objects.

Shinani spent most of the time coding and really enjoyed using the pre-trained extensions to make more complicated programs that replied to her voice commands. She was more interested in designing and coding interactions, rather than coding games.

By the end of the study the participants understood how sentiment analysis works after playing with the "Make me happy" project. They also learned how computer vision works and were able to train their own vision recognition model, test it and improve it. These children also understood that they could transfer their learning models and use them in different ways, in different projects. They really liked that feature, because it would allow them to collaborate when training a model, but after go and create their own projects using that model. Overall the children in this center gathered a solid understanding of how classifiers, sentiment and color detection work and why we need fuzzy logic when trying to program a device to talk to use naturally.

8.7 COLLABORATION

> Shivani: "Hey you wanna see what the actual sound I used is?" (She goes on to show Cleo how she changed the pitch of a bark using the Cognimates blocks to make it sound like a happy yip instead.) Cleo: "You're cute. You're cute. Aww, it only knows hello." (talking to the dog on the screen). Shivani: "Watch this. Cutie! Cutie!" (the starts to yip again). Cleo: "Woah! That's cool!" – Shivani 11 years old, Cleo 7 years old

During the different phases of the study, children engaged primarily in cumulative conversations (54.5%), followed by exploratory conversations (45.5%) – both listening to each other's ideas, building on top of them, influencing each other's opinions, and building projects together (see Fig.**??**). Empow had the highest score of collaboration (63.6%). On average, double than the collaboration score of all the other locations for the long-term study (see Fig.91). Compared to the previous public and private schools, these children worked together all the time, but this might have also been influenced by the small group size.

Participants behavior and language was video recorded, transcribed, analyzed and compared for each of the main coding categories: Communication, Cognitive and Social skills, Collaboration, Time spent Coding. Details about the coding scheme can be found in the Annex, see a.2. As seen in Fig. 104, there was a high score for most of the coding categories (>75%), except for coding time (48%) and presentation or demo time (25%).

This group was a wonderful example of how powerful collaboration across different age groups can be. While Shinani was an experienced coder with strong ideas towards the agents and AI technologies – she did not impose her views on the group. She was very patient with the younger participants. She enjoyed playing with them, and making programs that either would amuse them or challenge them to train new models and learn new things.

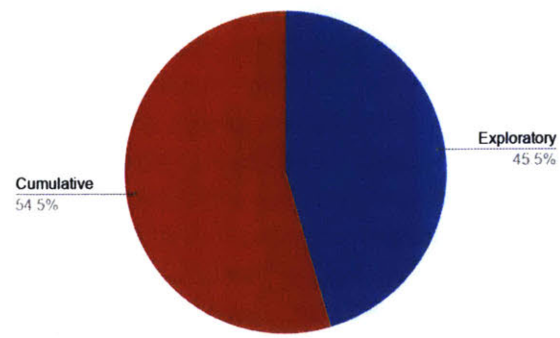


Figure 102: Types of conversations at Empow Center

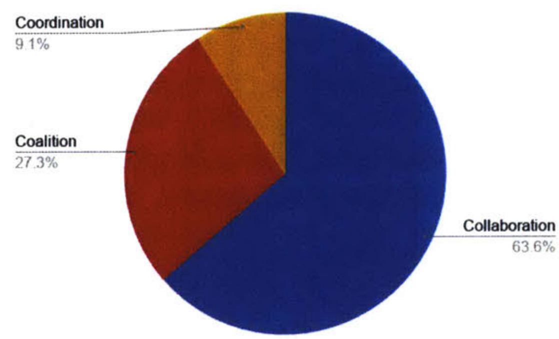


Figure 103: Types of collaboration at Empow Center

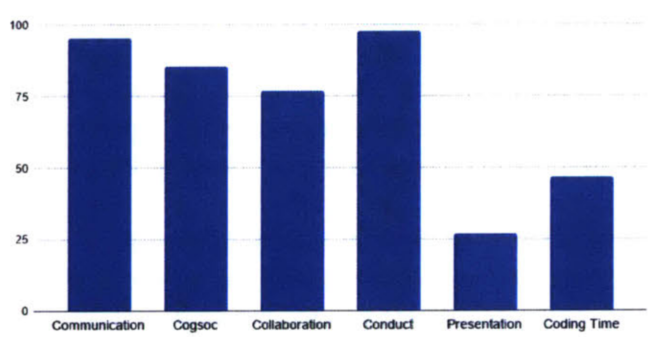


Figure 104: Distribution of observed children skills at Empow Center

8.8 REFLECTION AND INSIGHTS

In this group, both older and younger children enjoyed playing and tinkering together with the Cognimates platform and learned something from the experience. The workshops with Cognimates provided them with opportunities to individually tinker as well as to easily share learnings together – in addition to tips and funny moments. These are very important design guidelines for future platforms and tools for AI education. Based on these observations, we can easily imagine how to design a system that allows children to come together when training a model – to recognize images, sounds, text or different motions – and then afterwards encourage them to use that model in many different ways, in different coding projects, and share what they built with each other.

This kind of learning scenario provides the opportunity for children to collaborate on the harder parts of a project (training a model), and then afterwards use that model to put their own mark on what they want to build with that new capability. This not only encourages children to develop their own voice and identity through their projects, but it also allows them to learn how to transfer these newly acquired concepts and skills between different fields – as well as appreciate and consider other people's perspectives.

8.9 DISCUSSION : AI EDUCATION IN MEDIUM AND HIGH SES COMMUNITY CENTERS

Overall the Empow staff was very supportive. They assigned one of their staff to observe and help with the first session. However, because this is a private center and all the workshops are paid – I felt like many of the children had a client attitude and expected to be entertained by the activities.

The initial group of older boys who participated in the first interaction with agents were also more experienced programmers, like Shinani. However, they immediately dismissed the Cognimates platform as being too easy because they saw the Scratch blocks. They were mostly interested in being entertained by the agents and played with them, but they didn't want to spend time to teach the agents new things.

During the demo day with families, many of the parents were very interested in the Cognimates platform and spent time with their children testing the different programs. By the end of the experience, however, they always asked how much the devices cost and where they can buy them – ignoring the fact that all the digital Cognimates projects they used are available online for free.

In the case Empow, just like Shady Hill school, we saw that while children could be very excited to engage with the agents – they could

Figure 105: Family demo at Empow Center

also easily get distracted by them and switch from coding/training to just talking and playing with the devices. I believe this tension between entertainment and learning is here to stay, so then the crucial question becomes how do we design platforms and learning resources for a generation that has the expectation to be constantly entertained? This leads us to inquire how the agents themselves could play an active role in explaining their functioning, or coaching children when they are being programmed by them, just like in our Cognimates mission mode example.

9 AI EDUCATION IN ELISABETH PEABODY PUBLIC EDUCATION CENTER

> "Robots are not too smart because they are programmed but they can be programmed to be smarter than me", Sarah, 7 years old.

The fourth and last long-term study took place during the last 2 weeks of May at the Elisabeth Peabody House (EPH), a non-profit community center housed in a former church in Somerville, Massachusetts. The study sessions occurred three afternoons a week, for 1.5 hours each session. The workshop used a room in the back of the building that came equipped with 2 computers and a bookshelf. The children attending the workshops here come mainly from low SES families. The center would also provide children with snacks and occasionally school equipment. In this study we had a total of 15 participants, 10 of whom were boys, and 5 girls. All participated consistently throughout the 2-week study. Among them, 9 were younger (7 - 9 years old) and 6 were older (9 - 11 years old).

Figure 106: Elisabeth Peabody Center setup

9.1 PROTOCOL

Similar to those conducted at other locations, this study had 3 phases: initial perception and encounters with the agents, programming and training AI and post-activity perception test. But only 3 programming sessions per child, instead of 4, occurred. All the sessions were conducted by the author of this thesis and one of her undergrad interns who had received the appropriate IRB training and approval. The

Study Phases	Participants	Structure
Initial encounters with Smart Agents 1 Session	15 participants (10 boys and 5 girls) Ages: 7 - 9 years old - 9 ch. (5 boys and 4 girls) 9 - 11 years old - 6 ch. (4 boys and 2 girls)	1. Interact with 3 different agents(Alexa, Cozmo, Jibo) 2. Program the agents via their coding apps 3.Ask questions about perception of the agents
Programming and training phase 3 Sessions	15 participants (10 boys and 5 girls) Ages: 7 - 9 years old - 9 (5 boys and 4 girls) 9 - 11 years old - 6 (4 boys and 2 girls)	1. Discover and test starter ai coding projects 2. Complete study learning guides 3. Create their new projects and AI training models
Post-test perception 1 Session	8 participants (5 boys and 3 girls) Ages: 7 - 9 years old - 6 ch. (4 boys and 2 girls) 9 - 11 years old - 2 ch. (1 boy, 1 girl)	1. Ask questions about perception of the agents 2. Conduct interviews to asses children's grasp of AI concepts

Table 12: Protocol Elisabeth Peabody Center

team of researchers was consistent during all study sessions. The parents signed consent forms for their children to participate in the study. Children older than 7 also signed assent forms. Only 8 out of the 15 participants were able to participate in the last post-test activity. Participant details and demographics are represented in Table.12.

9.2 INITIAL ENCOUNTERS WITH AGENTS

Across the studies, the children at the EPH Center seemed to be most excited to encounter the agents as they had never heard of or seen them before. The children were especially mesmerized by the fact that the agents could talk in a human-like voice and express emotions. Cozmo robot was their favorite. Some younger participants wanted to play with and program only the Cozmo.

During the perception evaluation, the younger participants were unequivocal in their views of Alexa: that Alexa was smarter than

Figure 107: Children at EPH Center programming Cozmo and doing the perception questionnaire

Figure 108: Children testing the Clarifai vision extension and programming Alexa

them or that it would remember them. The Cozmo and Jibo robots received more "maybe" answers to the same questions. Overall the children perceived the agents as friendly and as having feelings, but they weren't sure if the agents could understand them or care about them. Similar to children studied at other locations, here, they would often address the perception questions to the devices themselves.

9.3 PROGRAMMING AND TRAINING PHASE

At this location, the participants did not have previous programming experience so when explaining the starter projects, a good amount of time had to be devoted to explaining the core computational structures like conditionals or Boolean variables. Some of the children had trouble reading and typing fluently, which also slowed down their programming process. Despite these challenges the children seemed fully immersed by the time of programming and training session and collaborated well while using the computers.

9.4 POST-TEST ACTIVITY

Only half of the children participated in the post perception questionnaire as some of them preferred to continue to code or play with the agents or were absent from the last session. Those who participated in the questionnaire spent a longer time explaining and debating their answers compared to when they were in the first perception survey. Overall, the children did not become more skeptical of the devices' capabilities after the programming and training phase; in fact, they believed even more that the devices are smart. However more participants said in the post-test that the agents do not have feelings. The results and changes to the perception questions are discussed in detail in the quantitative and qualitative analysis sections.

9.5 QUANTITATIVE ANALYSIS

Overall, we saw the majority of children changing their answers to the AI perception questions after the programming and training sessions, many of which to "maybe" (see Fig.??). Children became more skeptical toward the agents' ability to have feelings but not toward their intelligence or ability to remember. In the post perception, some of the children said the agents are smart because they are programmed to be smart. The following table describes the demographics distribution of children who completed all the phases of the study. We analyze their data in this section 11.

Students Young 6 Older 2 Girls 3 Boys 5	count	8.00
	mean	8.25
	std	1.22
	min	7.00
	25%	7.75
	50%	8.00
	75%	8.25
	max	11.00

Table 13: Table of Participants Age and Gender Distribution in Elisabeth Peabody Center

9.5.0.1 *Perception of AI Questionnaire*

We ran Shapiro-Wilk (S-W) test to check for normality ($p>0.05$) and Levene's test to check for equal variance ($p>0.05$), and hence chose to perform a sample t-test for proportions between pre- and post-questionnaire responses. Our sample t-test results showed that students changed their answers from "yes" to "no" when asked if the agents have feelings ($p = 0.1789$ for "no" pre-to-post). In the post questionnaire, there were no more "maybe" answers for the feelings attribution question ($p = 0.0085$ for "maybe" pre-to-post). None of the children said the agents would remember them in the post survey ($p = 0.0429$ for "yes" pre-to-post). Many of the children that initially said the agents "maybe" understand them changed their answers to "yes" and "no" at the end ($p = 0.2496$ for "yes" pre-to-post, $p = 0.2496$ for "no" pre-to-post, $p = 0.099$ for "maybe" pre-to-post). See Fig.111.

In comparison to the initial AI perception session, the children stopped addressing the questions to the agents. They became less categorical in their answers by switching their answers from "yes" or "no" to "maybe" (see Fig.**??**).

9.6 QUALITATIVE ANALYSIS

In the following section, I discuss how the children explain their perceptions of the agents, their most common coding and training strategies, and the influence of collaboration on their experience and process.

9.6.1 *Perception questions*

In the beginning, the children were playful with their questions posed to the agents ("Alexa is the tooth fairy real? Alexa is the Easter bunny real?"). When being asked if Alexa was smarter than they were, one younger boy responded "no" because "Alexa doesn't know everything, she doesn't know how I am feeling". He then proceeded to ask Alexa how he was feeling and confirmed the fact that Alexa did not know the answer. The rest of the children said Alexa was smart because of her having access to so much information. The younger children said the robotic agents might be smarter than they are, while the older children thought the opposite. Overall, the children described Cozmo as the agent that understood them the most, but also admitted that he doesn't always understand them either:"hmm I don't know... sometimes he does and sometimes he doesn't," said the 8-year-old Shanise.

Sometimes certain children would defend the agents in front of other children:

- "She does not have feelings", Alex, 7 years old (talking about Alexa)
- "What? How can you think she doesn't have feelings. If you say that to her she would probably say 'oh my god how could you think that'", Shanise, 8 years old.

In the post perception survey, the children still described the agents as smarter than they are, but justified their answers differently: "she is smart because she was programmed to be smart," according to the 11-year-old Jordan; while another younger girl (Sarah, 8 years old) said "not too smart because they are programmed but they can be programmed to be smarter than me." Some of them started saying that

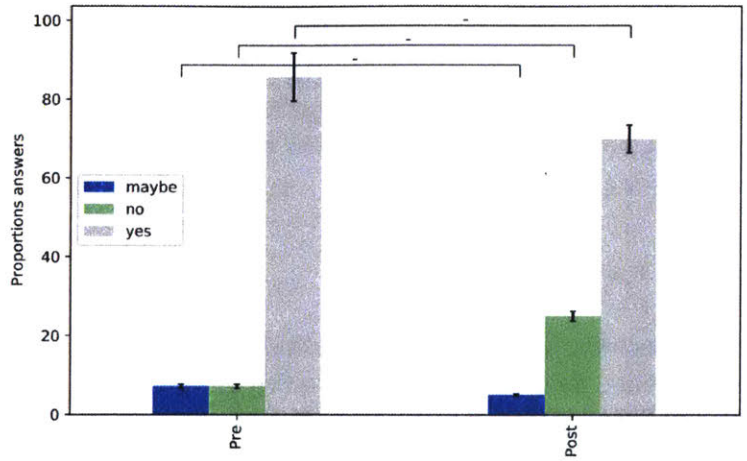


Figure 109: "Does the agent have feelings" answers Pre and Post at Elisabeth Peabody Center

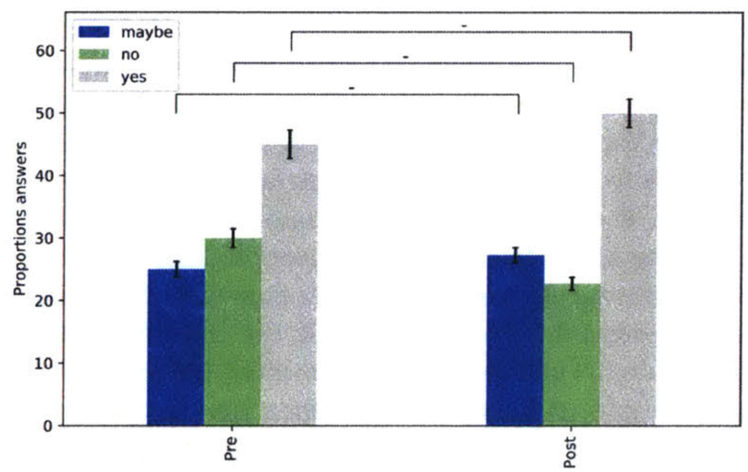


Figure 110: "Is the agent smarter than you?" answers Pre and Post at Elisabeth Peabody Center

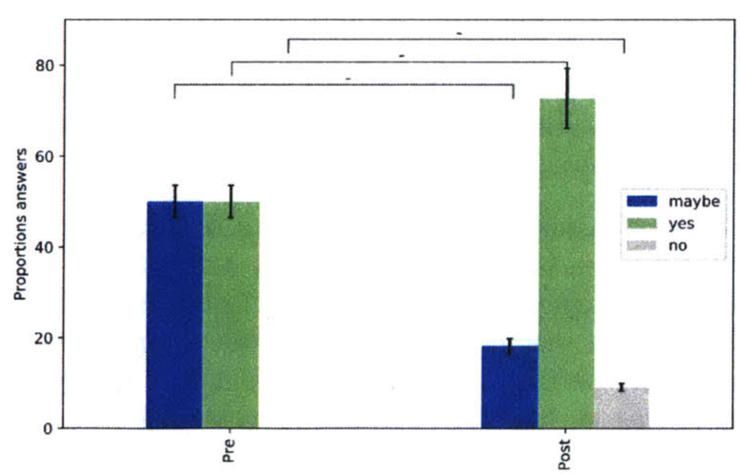


Figure 111: "Does the agent understand you?" answers Pre and Post at Elisabeth Peabody Center

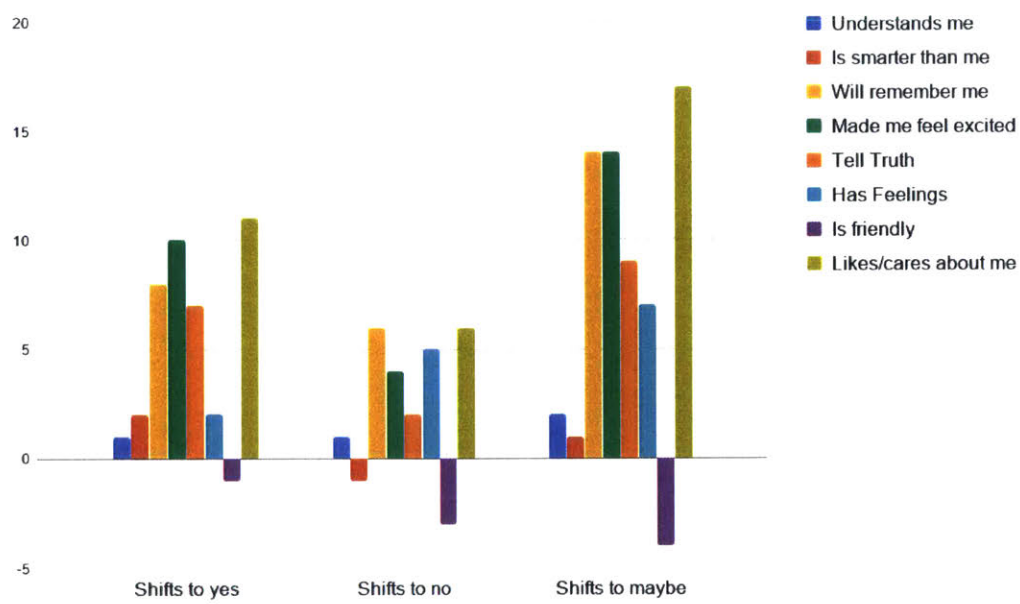


Figure 112: Answers shifts for each perception question at Elisabeth Peabody Center

the Cozmo is smarter because it knows "division and times" (something they discovered while programming it). Many would probe the agents with math questions before deciding how smart the agents are:

- "Because she know–is she a she?", Alex, 7 years old (explaining why Alexa is smarter)
- "Yeah shes a she", replied another girl
- "Because I only know times and plus and minus. Does she know division?" (Alex asks a division question)
- "Aye yai yai, shes smarter than me".

Those who discovered that the agents could take pictures of them or say their name said the agents will remember them: "that's easy because you just put your name into him and he remembers you," according to the 9-year-old Andres. At the same time, however, many became more skeptical of the the agents' truthfulness in the post-test because they understood that the agents could get information from the internet. "Not everything on the internet is true", said Andres, 9 years old. Later, Sarah, 8 years old, reused Andre's argument and said "Because it's the internet! Actually wait I'm in the middle the internet doesn't always tell the truth" and made all the other children in her group change their answers to middle also.

The older children described the robots to be more like animals, while the younger ones saw the robots as somewhere in the middle, between an animal and a person: "Animal and person I think. I like both. I think both because he knows what you're saying", said Hannah, 7 years old, while talking about Cozmo.

9.6.2 *Programming sessions*

The children managed to program the agents but most of them preferred to play with them or tele-operate them. While trying out different starter projects, the younger children would initially only describe in mechanistic terms how the agents work (e.g."you click the 'switch costume to happy"), and only after several sessions some of them would pick up the associated AI concept such as sentiment score or image recognition.

The children seemed to be post-rationalizing instead of thinking and questioning what they were doing while programming. They would prefer to try first all sorts of different examples, then try to explain how the extension might work. For example, when using the Sentiment extension, after trying a variety of different messages, Shanise and Jordan (8 and 11 years old) eventually were able to understand what words in their phrases would allow the extension to determine if a particular phrase was positive or negative. Some younger children would get frustrated at technical glitches (e.g. mic not working on a laptop) and appeared to have limited attention span for the programming sessions.

The older students really enjoyed programming Alexa and would pick-up the steps in activating the Cognimates skill on the device pretty quickly. They enjoyed that they could make the device remember their favorite things and also try to get it to say funny things (e.g. "Alexa what is my current age?" "100").

9.6.3 *Training sessions*

The children were very keen on building their own models (both with text and with pictures) and would spend a long time curating their text examples or gathering images of superheros, animals and costume parts.

Jordan, 11 years old, would spend a long time training a text model to recognize funny things and boring things. When it came to testing her model, she initially thought other people are also training her model and that's why it would classify certain phrases as "funny" even when she did not think they were funny. When the researcher asked her how she could confuse her model she chose the following example: "'doing funny homework'. Because I don't want to put more funny words or more boring words, because if I put like, 2 funny words and 1 boring word, it would probably put funny". Here we see she is starting to understand more accurately how the model

Figure 113: Children training a model to recognize superheroes and body parts at EPH center

recognition works and that every word in her example is being evaluated. Some of the students decided to train a model to recognize different elements of an Avenger. They chose suits, faces, arms, and helmet as their categories. After training the model, they didn't want to test it with images similar to the ones they already included in their initial examples. They choose to test it with images of Kirby and Barbie. The model predicted Kirby as a helmet. When being asked why, Shanise, 8 years old, said it was because Kirby was round like a helmet. She further explained that Barbie was predicted as a suit because she was wearing a superhero-like outfit. Shanise was able to guess beforehand that prediction. Jason, 7 years old, wanted to confuse the model so he chose a robotic arm instead of a human arm, but the model still predicted it as an arm. When being asked why, he said it's because the computer is also a robot and it would know everything about robots. In this instance we see that while some of the children were able to grasp how the image recognition works and make reasonable associations (e.g. Kirby looking round like a helmet), other students were still grappling to understand how the system really works (e.g. a computer recognizing a robot arm because it is a robot too).

When testing the vision model, students often thought that the color shift was the main reason why an image would not be recognized properly. Generally, they did not think about the object's setting in the image, its positioning, or whether it had other surrounding objects. For example, when Anton was testing the Dolphin-Puppy-Dragon-Orca vision model, and a purple-stylized dolphin was wrongly attributed, he easily noticed that the color may have confused the system. However, when he came across a picture with an orca that was in an odd position and surrounded by penguins, he had a difficult time figuring out what might had caused such a response in the system.

The children sometimes had trouble understanding the connection between the training examples and the Cognimates coding projects. They were confused about how typing examples on the "Teach AI" page could relate to how phrases were interpreted by the Cognimates

Figure 114: Children training a globe to respond to their commands

Text Prediction extension. The children who understood there was a connection described the process as "magic wire that went between the computers". Because of this, in future iterations of the platform we plan to make the connection between the training and coding pages on Cognimates more obvious and add a button that could allow children to toggle between the two pages.

Overall, we saw that children would describe both programming and training as "programming" and even after training their own models, they would still explain the agent's behavior in animistic ways (e.g. they said both Cozmo and the Dino program are "seeing with their webcam").

9.7 COLLABORATION

During different phases of the study, the children engaged primarily in exploratory conversations (55%), followed by cumulative conversations (35%) – where they added arguments and ideas on top of each and sometimes influenced each others' opinions (see Fig.**??**). EPH had the lowest score on collaboration (14.3%). Its participants engaged evenly in coordination (35.7%), coalition(28.6%) and cooperation(21.4%)(see Fig.91). Compared to the previous private community center, these children would work together but switched groups much more and formed less strong bonds.

As with the studies conducted at other locations, the participants behavior and language were video recorded, transcribed, analyzed and compared for each of the main coding categories: Communication, Cognitive and Social Skills, Collaboration, and Time Spent Coding. Details of the coding scheme can be found in the Annex, see a.2. As seen in Fig. **??**, the children in this center had the lowest score in coding time(20%) and conduct(77%) compared to those of other locations as they spent much more time playing with the devices– often getting enthusiastic, dropping the Cozmo robots on the floor or grabbing the devices from one another.

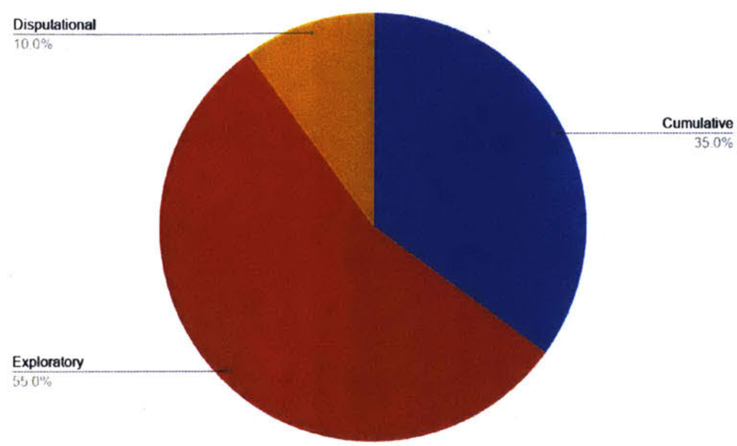


Figure 115: Types of conversations at Elisabeth Peabody Center

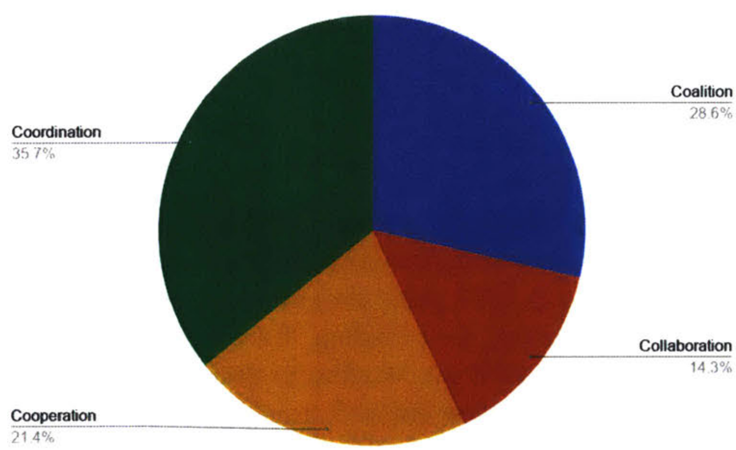


Figure 116: Types of collaboration at Elisabeth Peabody Center

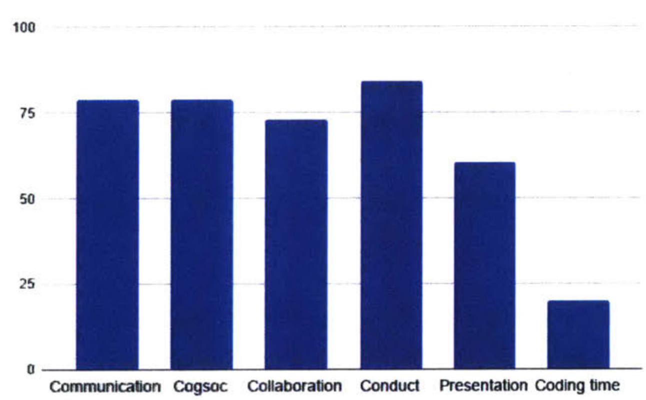


Figure 117: Distribution of observed children skills at Elisabeth Peabody Center

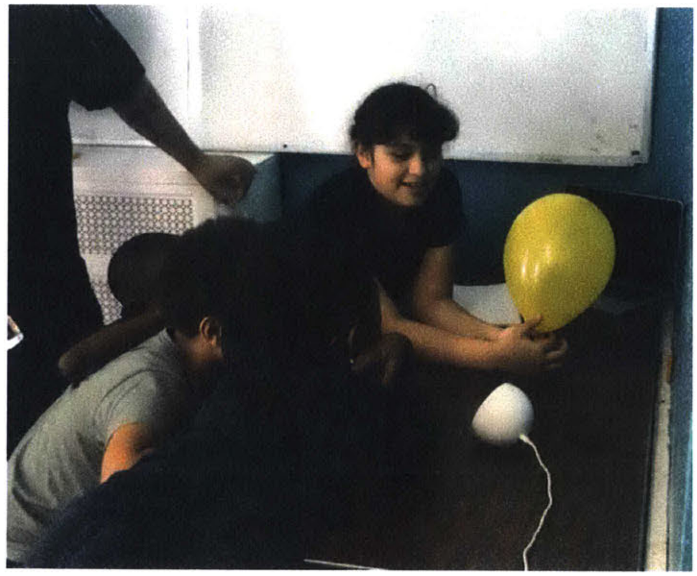


Figure 118: Children taking turns in talking to Alexa at Elisabeth Peabody Center

9.8 REFLECTION AND INSIGHTS

At this location, both older and younger children were really engaged in the study sessions and were enthusiastic about playing with the robots. However, with little prior programming experience, and having a harder time writing and reading, the children preferred to mostly play and interact with the starting projects instead of modifying the code. All the children enjoyed training their own models and spent a long time picking examples of images. But they weren't always able to understand how the system works behind the scenes and make a connection to how that relates to the agents. We saw that many of them described the agents as even more intelligent because they can learn and be programmed. At the same time, they described the agents as less likely to have feelings. In retrospect, I believe the children would benefit from having more coding sessions and more scaffolding for the them to go deeper into their understanding of AI concepts; but I consider this beginning encouraging.

9.9 DISCUSSION : AI EDUCATION IN LOW SES COMMUNITY CENTERS

I really like to contrast the experience with in Elisabeth Peabody Center with the experience in the ECSC after-school program. Both locations are based in East Somerville and serve mainly children from low SES families. But the ways they are managed are very different: the staff at the EPH Center was extremely close to the children and would encourage them to choose what they want to do, work on what they are passionate about. The older children and staff who were chaperoning the students were also genuinely interested in learning more about these technologies and continued to support the kids with programming after the study. We also saw less gender and age segregation at the EPH Center. I was impressed by the dedication and professionalism of the center staff and wish that we had more time to spend with the students. At this center we were not able to meet the parents.

10 INTERNATIONAL STUDIES

"I would like a social robot, it will help me with some other stuff without getting so like complicated" - Selma, 8 years old, Berlin Workshop participant.

Figure 119: German, Syrian and Italian students and mentors from Berlin workshop

In this chapter I will describe how children interact and perceive AI agents in three different European countries and compare them with children's interactions in U.S.A. Differences between participants of various SES backgrounds are also presented and discussed.

10.1 PROTOCOL

The international pilot studies took place in the following locations:

- Redi School: This is an NGO based in Berlin, Germany, which is running coding workshops for Syrian immigrants, while trying to help them get a job. Our study was organized for the families of their students, other German and Italian children from their community also participated.
- Billund International School is a private affluent school based in Billund, Denmark. The school was created mainly for the children of LEGO employees (LEGO headquarters is based in Billund). It hosts students of different nationalities, who are very familiar with programming and maker education.

Location	Participants	SES	Nationality
Redi School Berlin Germany	10 participants 5 girls, 5 boys 1 younger 9 older	Low & Medium	German Italian Sirian
International school Billund Denmark	21 participants 7 girls, 14 boys 19 younger 2 older	Medium & High	Danish British Mexico India
STEAM center Skellefteå Sweden	15 participants 2 girls, 13 boys 8 younger 7 older	Medium & High	Swedish Korean Romanian
East Somerville School USA	27 participants 9 girls, 14 boys 16 younger 11 older	Low & Medium	Latino American Indian
EPH Center Cambridge USA	15 participants 5 girls, 10 boys 9 younger 6 older	Low	African - American Indian Rusian
Shady Hill School Cambridge USA	16 participants 6 girls, 10 boys 10 younger 6 older	High	American

Table 14: Summary pilot studies

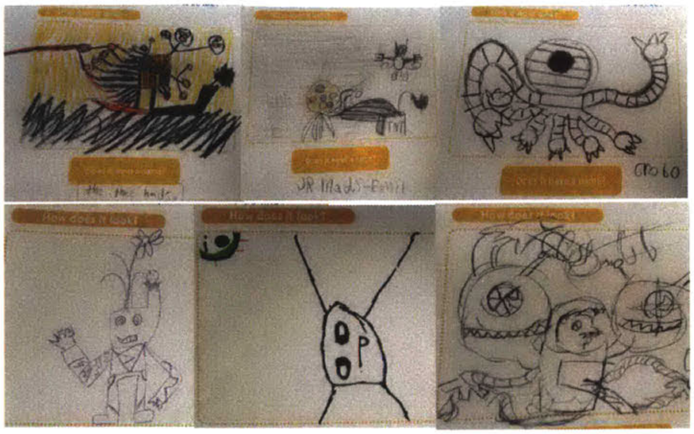


Figure 120: Drawings made by children in Denmark and Germany when ask to imagine future AIs

- STEAM Center Skellefteå is based in the north of Sweden and is a public community science center. The workshops in this location were organized in collaboration with the Creative Summit, which took place in the same city and where the author of this thesis was presenting her research.

The international studies consisted of one session which lasted 1.5h - 2h. During the session, children were asked to draw and imagine the future of AI agents. After, they were introduced to different AI agents (Alexa home assistant, Jibo and Cozmo robots). First they would play and talk to the agents, and after they would also get to program them with their dedicated commercial coding applications(for Alexa they would use the Cognimates extension). At the end of the session, we would ask them questions about how smart, friendly, truthful they thought the agents are (see Appendix for full perception questionnaire).

A summary of children's demographics, nationalities and SES is presented in Table.14 . We compared the perception results with the findings from the initial perception studies we ran in U.S.A schools and centers(East Somerville School, Elisabeth Peabody House Center and Shaddy Hill School). The sessions in the international locations respected the same format as the first sessions in the long-term study locations, so the responses to the pre- perception questionnaire are comparable.

10.2 DESIGN YOUR FUTURE AI

In Denmark, Germany and ECSC public school in Somerville, I asked the children to make drawings of how they imagine their future AI agents to be like. I also invited the participants to describe in their sketches what they would like to teach to their agents, and what are the main uses they imagine for them.

Children from all the locations drew things like robots, animals, things that can play games. Only the kids in U.S.A drew Alexa and explained how devices are working. The children in Denmark had more abstract and more complex drawings (Scifi characters, abstract toys, games - Fig.120). Only the kids in Berlin drew school like creatures (walking pencil, bears like coming from a kids book) Small children drew small robots.

10.2.1 *What did kids wanted to teach the AI*

The children wanted to teach the AI, or the robots from their drawings, many different things (except for a few children, who said they either want to teach it everything or nothing). Several times, the children wanted the AI to help them do things they cannot do, like reaching for tall things, or help them with chores that are hard, like math and homework. All the categories of abilities that children wanted to teach the AI are summarized bellow:

- Self benefit:
  - give them candy, chocolate, cake
  - make food
  - carry things
  - reach to things
  - take care of them
- Personalization:
  - learn their name, age, location
  - learn what they like
  - predict how long they will live
- Do Fun things
  - play different sports
  - play an instrument
  - do tricks
  - play games
- School related skills
  - write words
  - do math
  - do their homework
  - learn different languages
- Deterministic

- everything
- nothing

Some of the children were very thoughtful when thinking how AI and robots could be used in the future. Selma, an 8 years old Syrian girl who attended the Berlin workshop, said she would like a "social robot" explaining: " Yeah, helps me with life. Yeah, like, I'm a weird person, so when someone hurt themselves, then I can't look because I don't like it. And then like, I have a friend that I say that I, I always play with him, but I don't want to say that I don't want to play with you I want to try others then I always try and then it doesn't work and then I stop being sad and the I don't anymore and then I get confused and the social robot will help me with some other stuff without getting so like complicated".

Laya, a 7 years old student at Shaddy Hill private school in Cambridge, also said: "That they're like, playing with it, so if they were really lonely, and they had like a big house and not that much people, or if people didn't want to play with them and they had a big house, they would play with Jibo, so then it would be like really fun. Or they could play with Cozmo."

Fadah, a 8 years old student from ECSC public school, said that she would like to have a wearable AI, that could help her call 911 when needed.She also wanted the AI to protect her, or help her get food and money for her family.

In the examples we observe how children from low to high SES, public to private schools, different origins and geographies, imagined that future AI should help people. While sometimes they described it in whimsical and utilitarian terms, they were also able and willing to imagine more profound ways in which these technologies could impact their lives.

10.3 INTERACTION WITH AGENTS AND PERCEPTION

10.3.1 *Redi School Berlin*

The participants in Berlin school were of mixed ages, ethnicities and had varied prior experience with coding. They were very good at collaborating, both for sharing the equipment and for helping each other with programming. They had heard about Alexa before, but never interacted with one. They never heard about Jibo and Cozmo and were very excited to play with them. We organized two consecutive session in this location, due to the high number of children who wanted to participate in the study. Some of the children were so captivated by the robots, that they decided to participate in both sessions. Overall, children were much more skeptical of the AI technologies, but really enjoyed interacting with the devices and described them as friendly.

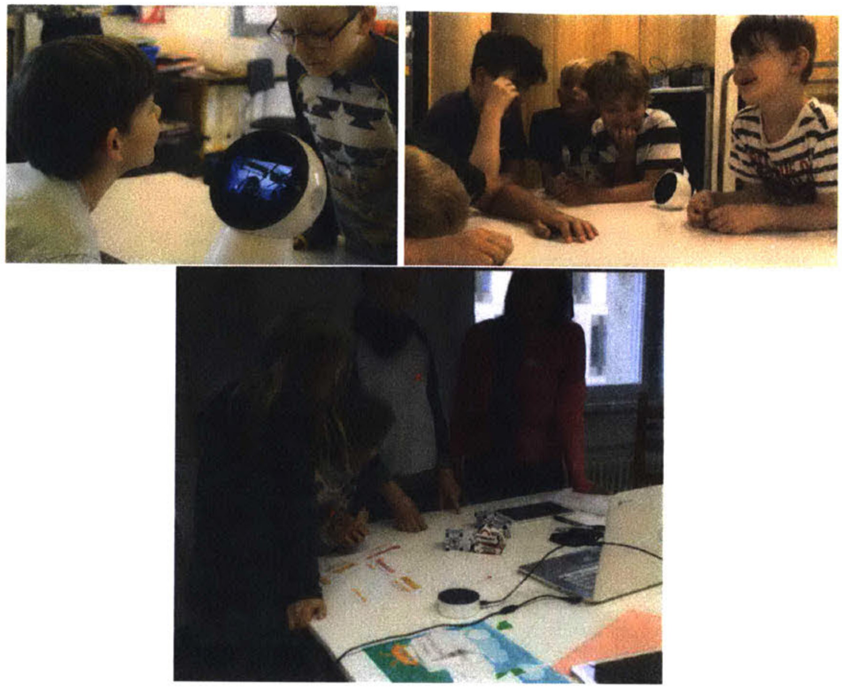


Figure 121: Children interacting with the agents during the study in Denmark, Sweden and Germany

When asked if the agents have feelings, students answered with a categorical "no" for Alexa. They said the robots have feelings, but explained:"Cozmo has feelings because the people that made Cozmo programmed a lot of emotions", said Yael, 8 years old. Saveeta, an 11 years old girl added: "Cozmo has feelings because of animations that reflect each feeling".

When explaining how the agents understood them, participants always referred to coding. If a device would not run their program as they expect it, they would say it didn't understand them: "Jibo doesn't understand because I coded a program for Jibo to repeat 5 times, but the program didn't repeat properly", said Saveeta.

The older children said Alexa was smarter than they are, but not the robots. They also thought Alexa didn't really understand them. Many of them changed their opinion when they saw the device can speak German.

One of the girls thought Alexa had problems to answer all her questions because of its connection to the internet and said: "I really liked the Alexa because it was kind of funny as well, uh, it was funny and it was also kind of like weird because she couldn't't answer all the questions, but I think I know why now "(why?) "Because she didn't open the internet so much for all of the questions because they put internet in Alexa which can be so smart but she didn't, uh, she didn't, uh, didn't get all of the internet stuff that she can learn about so I, like, so she doesn't answer all the questions", Selma, 8 years old.

The same girl argued that people are smarter, because they are independent and have brains: "Because people can do all the stuff by themselves and get um like made faster and they can like, they have legs. But robots, not all the robots have legs so they can't do everything by themselves they don't have a brain, so they don't know where, what they're doing, or where they're going probably. So we might say smarter means you concentrate more on your brain, so they don't have any brains so we might be smarter". She later added that in the future people will make robots with brains but they will be "laser brains".

10.3.2 *Billund International School*

All the participants in the Billund International School were younger (7 and 8 years old). These children were fluent with coding and new technologies, but they had never used the agents before. In general, they would dispute a lot when having to take turns interacting with the agents, and didn't like to share the study equipment (tablets, robots etc).

During the interaction with the agents, participants were very good at making logic associations when trying to figure out what questions the devices might know how to answer:

- "Hey Jibo what is the color of the stars?", asked Bella, 8 years old (the robot didn't know how to answer"
- "I think I know how to ask it.. Hey Jibo who is Louis Armstrong?", asked another 7 years old boy while trying to figure out what space related people Jibo might know.

They described the devices as friendly and caring, but when a 7 years old girl, Cami, said the devices "don't know us that well", the rest of the children in her group changed their minds about the caring part.

Children explained that devices that listen to them, such as Alexa and Jibo, understand them and these agents can "kind of remember them" because they took pictures of them. They were vehement when it came to the feelings question and said: "a robot can't really have feelings, he can only act like it" (they called Alexa a robot also).

When it came to the intelligence attribution question, students said Cozmo is not smart because it "cannot talk or do math" . Jibo was in the middle as "he knows a little more because he is bigger" said Cami, 7 years old.

When some of the girls discovered Cozmo had a camera, which is very small and not very apparent at first, they changed their opinion about the robot nature:

- "It's a great spy cam. People think he's so innocent, but he's actually evil", said Bella, 8 years old

- "Cozmo is innocent, but in real life he's evil", added another 7 years old girl nearly screaming

Not all the participants got to program Alexa, but the ones who did said "she likes and cares about us more now".

Figure 122: Participants discussing about AI and their perception of the smart agents (Sweden, Denmark)

10.3.2.1 *STEAM Center Skelleftea*

Just like in Berlin, the children at the STEAM center in Sweden were of mixed ages, ethnicities, and had varied prior experience with coding. Overall, the children were good at collaborating and sharing the equipment. The older children were quite advanced with programming, and managed to build more complex programs with Cognimates. All the participants and would pair well when using the computers. None of them had encountered or used the agents before, but some of them had heard of Alexa. The younger participants would only speak very little English, but the local mentors and older children would help them translate.

The younger children would mainly ask the devices to play music or open games, and they enjoyed tele-operating Cozmo and programming it. These children would also program together multiple Cozmo robots, and make them build a structure together by using their cubes.

When asked if Alexa is smarter than she is, one of the older girls replied: "I don't hope so" and another older boy added "She is not smart because she didn't know the capital of Sweden, she is only American, not Swedish". Most of the older children concluded Alexa is only smarter than they are in some situations, "50/50" smarter as one child described it. They also wanted to teach Alexa their names and program it. Older participants described Cozmo as intelligent, because he can "react to things", but said it is not smarter than they are.

The children debated a lot if the robots should be programmed to make people happy:

- "You should never program a robot to make you happy" said Mario, 7 years old

- "Yes because then you play no more with your friends" added Joerg, 11 years old
- "Phones make us happy and they are robots too", said then Alex, 8 years old
- (Do you think phones help people?)
- "Yes but they also make people more stupid because they don't learn" replied Joerg
- "Robots will never be like humans, they can act like humans but they will never be like humans", concluded Hans, 11 years old.

Figure 123: Children programming with Cognimates in Sweden and Denmark

10.4 QUANTITATIVE ANALYSIS

In order to compare the perception questionnaire answers between the different locations, I compared the proportions for each of the answers, using the "N-1" Chi-squared test as recommended by Campbell and Richardson [13, 54]. The confidence interval was calculated according to the recommended method given by Altman et al [3].

10.4.1 *Intelligence attribution*

When answering if the agents are smarter than they are, children in Berlin were the most skeptical. They had significantly less "yes" answers than children in Sweden ($p = 0.0437$), Denmark ($p = 0.03816$) and EPH Center in U.S.A. ($p = 0.015$). The "yes" answers for the intelligence attribution were comparable between Berlin, Shady Hill Private school, and ECSC Public school. Berlin recorded the highest number of "maybe" answers to the same question, significantly different than the children in Sweden ($p = 0.0139$)(see Fig.124).

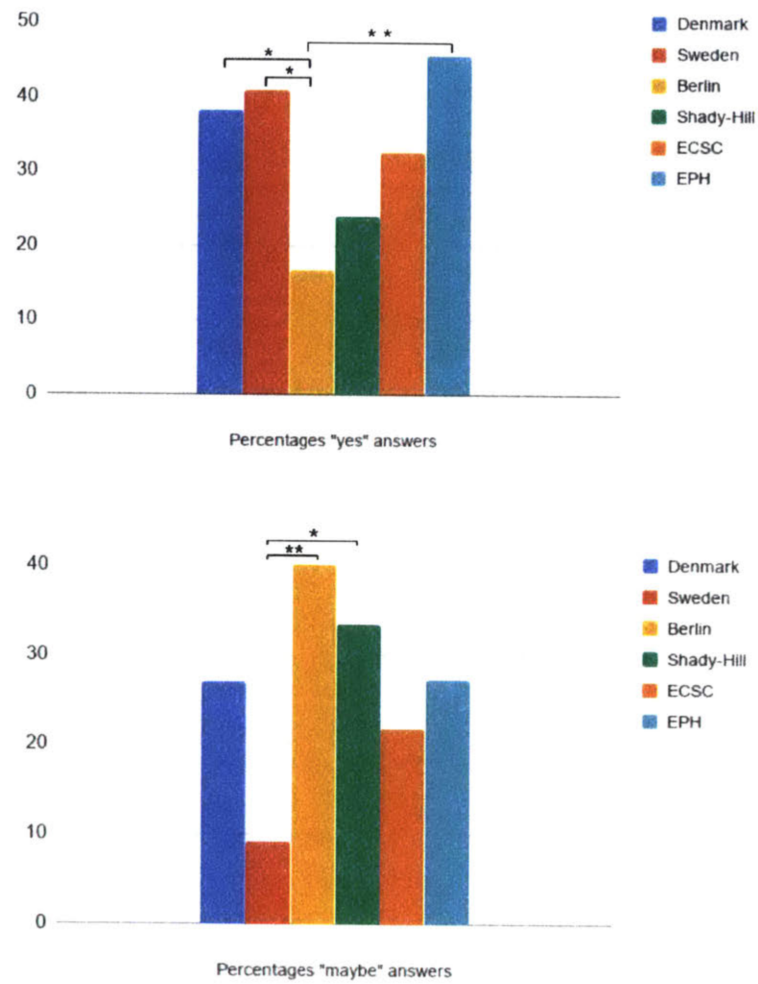
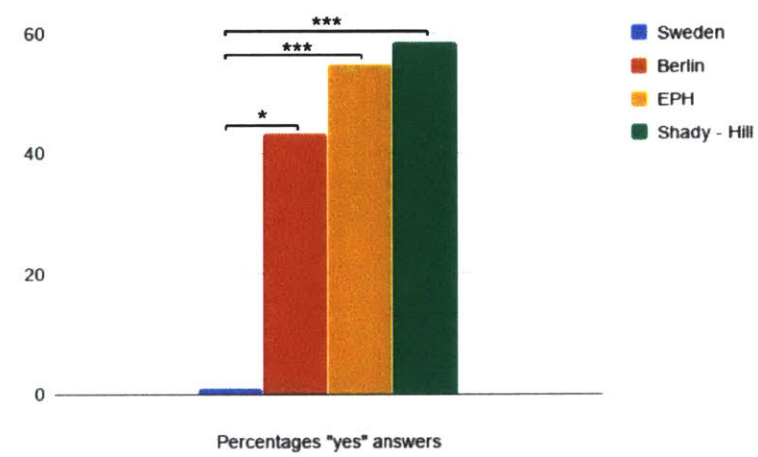


Figure 124: Comparison of "yes" and "maybe" answers to intelligence attribution question across all the locations, * $p<0.05$, ** $p<0.01$

10.4.2 *Truthfulness attribution*

Swedish children were the most skeptical when answering if the agents are truthful, with less than 1% answering "yes". The "yes" answers for the truthfulness question, were significantly different between the Swedish and the U.S.A children($p = 0.0007$ - Shaddy Hills school, $p = 0.0003$ - EPH center). The answers in Sweden were also significantly different when compared with the school in Berlin ($p = 0.0028$). When analyzing the "maybe" answers to the same question significant differences were recorded between Sweden and Shady-Hill school, with more "maybe" answers in the Swedish school ($p = 0.0172$). See Fig.125.



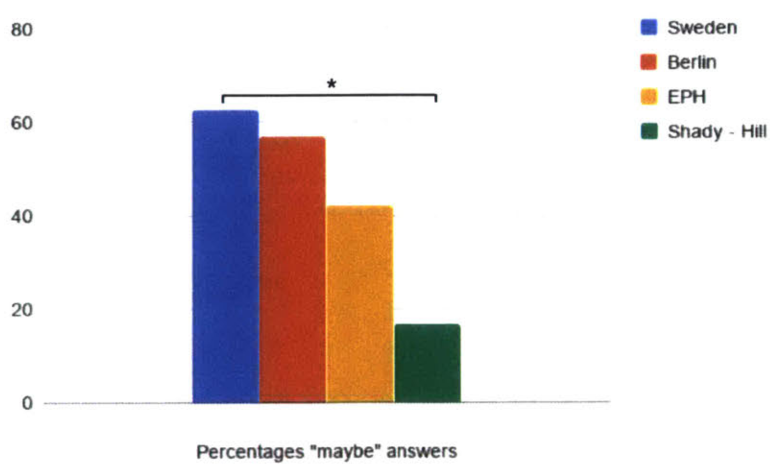


Figure 125: Comparison of "yes" and "maybe" answers to truthfulness attribution question across all the locations, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

10.4.3 *Perceived understanding*

Children in Sweden were the ones that reported the agents understand them the most(68% "yes" answers) and EPH center children were the ones that said they were understood the least (40% "yes" answers). Shady-Hill students had the highest number of "maybe" answers. Their answers were significantly higher, when compared to Swedish children($p = 0.0151$).See Fig.126.

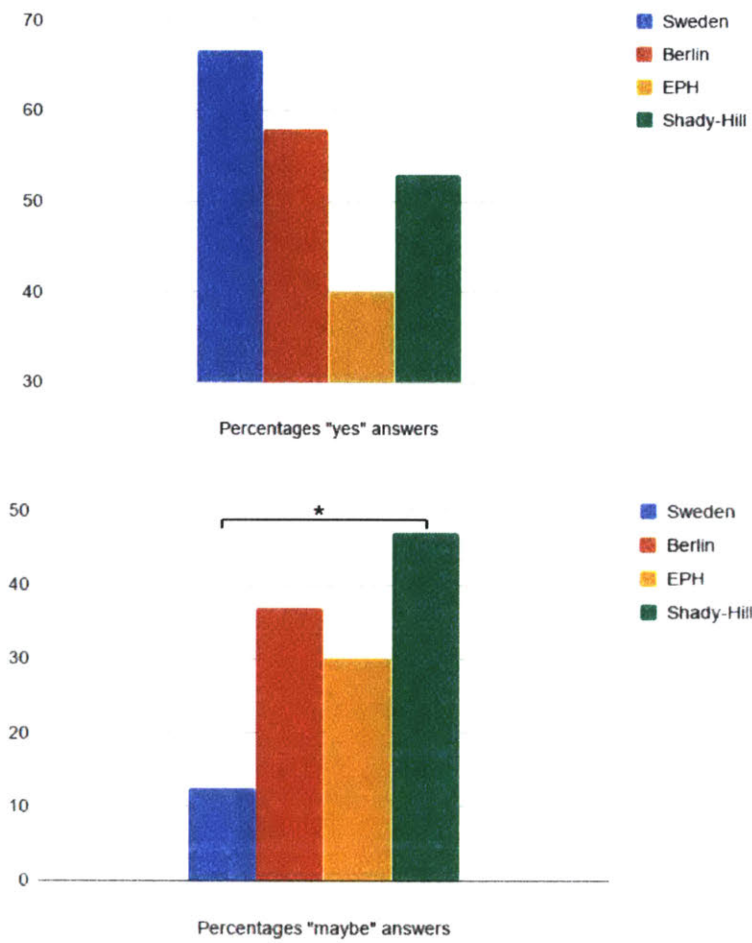


Figure 126: Comparison of "yes" and "maybe" answers to understanding attribution question across all the locations, * $p<0.05$

10.5 REFLECTION AND INSIGHTS

It has been clearly recognized by now in children development research that learning doesn't happen in the void. Besides the immediate intrinsic and extrinsic factors that influence the way children learn, there is also a socio-cultural dimension that is important. Cognitive – and human – development, according to Vygotsky, is a result of a "dynamic" interaction between the individual and the society. This dynamic relationship denotes a relationship of mutuality between the two. Just as society has an impact on the individual, the individual also has an impact on society. In this context the social and cultural settings where the children's activities take place require social interaction and communication. Children learn best through social interactions, and these interactions are defined by the culture and the social-economical environment they grow up in [31, 37]. This approach to situated learning motivated us to explore and compare how children interact, and perceive computational objects in different geographies and SES communities.

Our findings show that children in Europe were overall more skeptical of the agent's smarts and truthfulness. When it came to describe how much the agent understands them their answers would be similar but the justifications were diverse, with children in Europe associating understanding more with coding and kids in U.S.A referring more to the voice conversations. I believe this difference in their explanations is due mainly to a more limited representation of voice technologies in European countries.

The European children would be more skeptical of the agent's intelligence and truthfulness at first, because they didn't really know what the devices can do, or because they heard critical conversations about AI technology at home or in the news. However, when they got to interact with the agents, some of them would get really enchanted, but they would maintained their stance that these technologies should be kept at a safe distance(not program them to make people happy) even if they are fun to engage with.

The younger children in all locations would not dissociate programability from the agent ability to have it's own identity and agency. For example, the 7 years old students in Denmark, thought Alexa cares more about them because they are programming it. Meanwhile, the younger children at ECSC school, assumed Cozmo might get upset because they are programming it, and thus controlling it.

The international participants were often disappointed when the agents didn't know more about their country, or couldn't speak their language. Overall, all the participants were excited to try the Cognimates Alexa extension and teach the device things about their culture.

One of the Syrian mothers, participating in the Berlin workshop, asked me what I expected to find different when working with children in different parts of the world. She added that children these days are not so different around the world, because they grow up with the same technologies, and are all part of a global community, via the internet. What I did found to be similar in all of the locations, was the richness of children's analysis and their ingenuity when playing, probing or programming these devices. I was also happy to see

Figure 127: Syrian and German parents coding together with their children

that they understand why it is important for people their age to learn about AI.

In all the international locations, the parents were engaged and involved, and sometimes, just as curious as the children were. The parents were happy to discover that their kids can use these technologies in constructive ways, by programming them and wrote down the name of the Cognimates platform, to encourage their children to continue to use it at home.

11 ROLE OF TEACHERS

"This was one of the most cutting-edge and yet kid-friendly lessons I have ever instructed as a STEAM educator; Cognimates provides an extremely kid-friendly introduction to AI and ML components and builds upon Scratch in a very intuitive way so that students feel comfortable with the interface but feel challenged and excited by being able to experiment with various AI/ML extensions" Danielle Olson, STEAM educator at MIT.

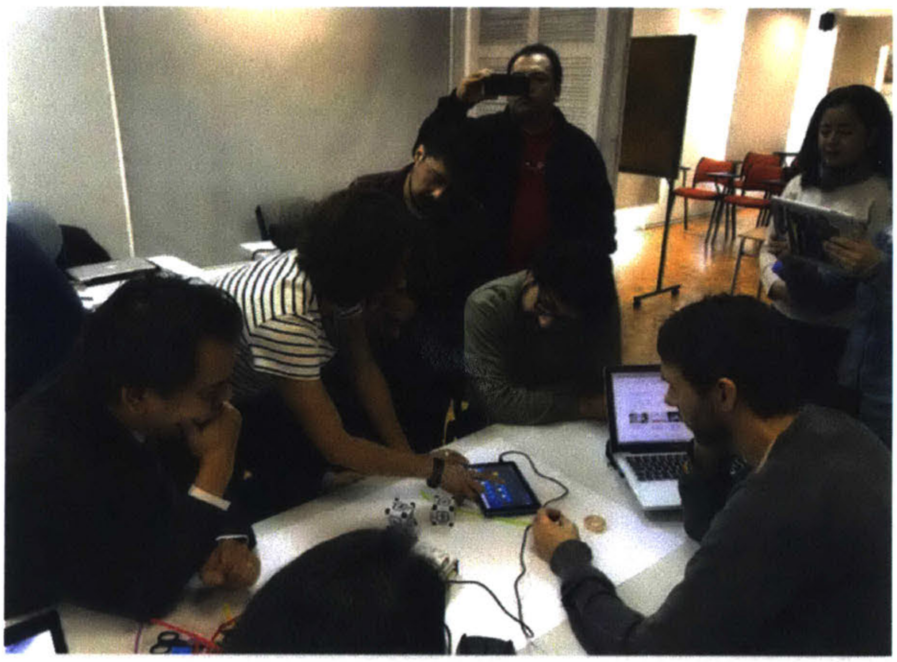


Figure 128: Group of teachers in Chile participating in a 2 days Cognimates training

There is no doubt that teachers need to be central agents in the next phase of AI education as they will be the orchestrators of when, and how, to use the AI technologies both at home and in the classroom. More than this, teachers – alongside learners and parents – should be central to the design of Ai education tools and platforms, and the ways in which they are used. This participatory design methodology will ensure that the messiness of real classrooms or home environments is taken into account and that the tools deliver the support that both parents and educators need.

After the development of the Cognimates platform, I had the opportunity to engage with several groups of teachers and STEAM educators and teach them how to used it. I will describe each experience below, and show what strategies of collaboration and co-design were most successful.

11.1 WORKSHOP FOR TEACHERS AT STEAMCONF IN BARCELONA

STEAMConf is an annual conference at Cosmo Caixa, a science museum in Barcelona, Spain. STEAMConf invites educators, researchers, and artists to explore concepts in STEAM education in hands-on ways. The conference is founded on the idea that tinkering and making is "a method for exploring and understanding our changing world through science, engineering, technology, art and maths," and offers workshops and keynotes in Catalan, Spanish, and English. This year's focus was on programs and resources that can minimize the digital divide, and remedy gender imbalances, and promote equal opportunities. Most talks focused on maker and STEM education, the learning theories behind constructionism and tinkering, creating equity and community through education, and venturing into AI and intelligent robotics. The participants to the Cognimates workshop were

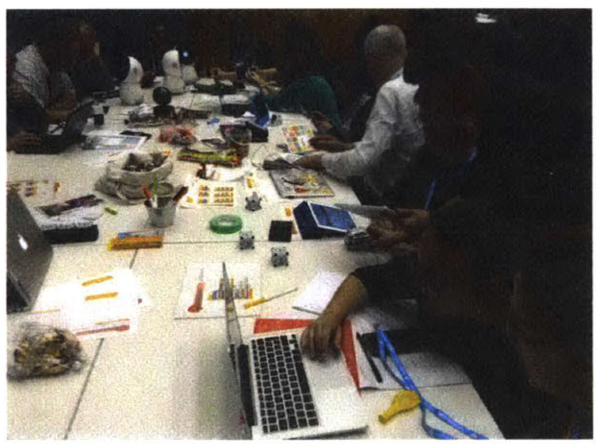


Figure 129: Teachers, Museum currators and STEAM educators participating in the Cognimates workshop at STEAMconf in Barcelona

both teachers and STEM educators working on museums and public libraries from Spain, France, Netherlands and Ireland. They had very diverse backgrounds and experience with technology. There were 15 participants in total. The workshop started with a small introduction from all the participants where they also mentioned what the expect from the experience and why they are interested in AI education. Most of them were interested to learn how to use this new technology so they can share and teach the youth back in their communities. The workshops was very hands-on. I demonstrated how a starter project works on Cognimates and how they can load new ones and invited them to play with all the starter projects in our gallery and then create new ones. The workshop concluded with a demo where all participants showed what they built and like the most.

The participants worked in pairs both on laptops and on tablets. Some of them were very curious and made a point to try all starter projects and try to connect to as many devices as possible and program them. Other participants were more interested in exploring a specific concept and functionality and build their own project around it. We didn't get around to test our vision or text models as part of the workshop but I showed them how they can do it at home.

One of the common bugs we found was that the voice recognition would only work for the language in with the OS of the laptop is setup, so if the OS is in French the Speech extension would only recognize French language. We also found that the extensions using the camera do not always load properly. Many of the participants raised the issue of limited or slow Wifi connectivity in their spaces and we brainstormed about ways to mitigate that in the future. At the moment the Cognimates platform can only be used if the computer or tablet is connected to the internet however it is technically possible to make it work offline by downloading a compressed version of the AI models used by the different cognitive services and using them locally.

Overall the teachers loved the flexibility of the platform, the variety of extensions and how easy it was to start playing with the starter projects. They told me they would also like to use it for building bigger installations or exhibitions with the students (especially referring to the hardware extensions).

It really help that the group was so diverse in terms of backgrounds and that it included also people working in museums and libraries which inspired the teachers to imagine learning in a more broader way.

11.2 TEACHER TRAINING IN CHILE

The teacher training in Chile was organized in partnership with the British University of Chile (UBC) who is already organizing and running technology training for teachers all across the country. One of the senior academic director at UBC had come earlier to MIT Media Lab on a teacher tour and saw a demo given by the author. She then asked the teachers in Chile if they would be interested to learn more about AI education and because there was a lot of interest she helped organize a local teacher training. The training lasted two days with sessions of 6 hours per day. The participants were K12 teachers from various provinces of the country, a group of people working for the Ministry of Education of Chile, a movie director and a PhD student in neuroscience. There were 20 participants in total. The training was done in Spanish and many of the materials and projects had to be translated from English.

In the first day the participants formed groups and they spend time researching while preparing a 5 minutes presentation to address the following questions posed by the author:

- What is AI?
- Why is it important for people to understand how it works?
- How can we use it in the classroom?
- How do you imagine it will be used in the future?

The groups really enjoyed doing this research and some of them spent a lot of time debating. When presenting they realized they do not have a common and clear definition. Many of them touched on the importance of teaching children about the ethics of AI but had still quite abstract ideas on how to actually do that in the classroom.

After the presentations they got the opportunity to play and explore with different existing AI interactive demos like Teachable Machine or Find Emoji from Google. They most common use case they imagined for the classroom was to use interactive image recognition platforms for language learning. The first day concluded with them testing some of the digital Cognimates extensions (Sentiment, Color, Clarifai, Twitter).

The second day started with them encountering and programming Alexa, Jibo and Cozmo. In the case of Cozmo they were given the specific task of making it draw a spiral with it's movement and a pen attached on a piece of paper. After got back to Cognimates and try to combine the programs they used the day before with the extensions they used for programming the agents and their challenge was to make one of the agents react to the feelings of their messages. Some of them went further and made the robots react to their tweets or specific words they were saying. We concluded the training with a round table discussion about their experience and how they want to continue to use these technologies.

Some of the participants expressed the fact that they felt limited because they didn't know Scratch better before coming to this workshop and that they wished there was a pre-workshop teaching them how to use Scratch first. Participants were divided when it came to the topic of more theory vs practice. Half of them wanted more theory while the other half said that the current model worked quite well. One of the female participants who is teaching robotics in her school expressed her frustration with the fact that the school doesn't trust her enough to let her teach a technical lesson and always sends a technician to her class to sit next to her. She invited all the participants to reflect on how we can attract and involve more women in this field. This sparked a vivid debate among all the participants which mostly agreed that the gender bias in access to science and technology is often projected by teachers and needs to be addressed. Some of the training participants were very focused on the devices (Alexa and robots) and complained these devices are not easily accessible in Chile. With the support of other participants I explained how the focus on the AI education should be on the process and concepts and how they can still teach these concepts event without the smart devices. The discussion concluded with all the participants recognizing that they need to go beyond the amazement phase of this technology and find ways to leave their mark on it together with their students.

Figure 130: Examples of teacher training conducted in Denmark

11.3 TRAINING FOR TEACHERS TRAINERS AT MIT STEAM CAMP IN HONG-KONG

The MIT STEAM Camp is organized by the Office for Digital Learning(ODL) at MIT in collaboration with the Chinese International School (CIS) in Hong-Kong. This year marked the second edition of this event. The goal of the camp is to empower students to solve real-world challenges in areas of need, such as energy, education or health. The camp is held on the CIS campus during a period of two weeks. The children who participated this year were supposed to have completed Gr 4/ Primary 4/ Y5- Gr 8/Secondary 2 /Y9 /Form 2 by the end of the 2017-2018 school year in Hong Kong. The camp also hosts a professional development course for both CIS and non-CIS teachers simultaneously to the children workshops. Both the camp and teacher course were delivered in English. The theme of the camp this year was "water" and I obtained a grant from OLD to develop a special Cognimates module entitled "Waterkinesis" that would allow children to control LEGO robots in water with their minds. The main idea was that students would program and train the machine to recognize patterns in their brain activity and map the robot motions to it. Together with one of my undergraduate interns, Lauren Oh, we developed all the materials needed for this collaboration (curriculum, prototypes, materials) and trained and MIT Phd student, Danielle Olson and an MIT graduate student, Lily Zhang to run the activity and the teacher training on the ground while supporting them remotely. Two groups of 28 students ages 12-14 participated during two days sessions (4 days of sessions in total). Twenty teachers participated in the professional development sessions.

Figure 131: Example of Cognimates activity ran by MIT mentors at MIT Hong-Kong STEAM Camp

This was the most complex collaboration I undertook to date with teachers and students, not only because it involved electronics and water but mainly because it had to be orchestrated much in advance and supported remotely and the activity will take place with so many students during multiple days.

We initially prepared a starter project, an activity sheet and video demo for this project. While talking both with the Hong-Kong teachers and the MIT mentors we realized that many more documents and materials need to be prepared. So we created a safety waiver, a master guide for the teachers walking them through all the steps of the project and platform use, providing debugging tips and steps, a lesson plan document and a series of quizzes for evaluating what concepts children learned in the activity. All these materials are included and listed in Appendix.

In the end the module was a success and this is a fragment form the feedback that one of the MIT mentors sent to us after the camp: "This was one of the most cutting-edge and yet kid-friendly lessons I have ever instructed as a STEAM educator; Cognimates provides an EXTREMELY kid-friendly introduction to AI and ML components and builds upon Scratch in a very intuitive way so that students feel comfortable with the interface but feel challenged and excited by being able to experiment with various AI/ML extensions", Danielle Olson.

These initial experiences of working with educators and co-designing learning activities showed me how crucial and meaningful their contributions are, both when it comes to finding best pedagogical approaches and methods to introduce these new concepts and for figuring out best strategies to introduce these lessons in the classrooms. A lot of the effort and work has to be concentrated on the design and iteration of curriculum together with adaptations and simplifications of the technologies used to support it.

12 CONCLUSION

"Not building machines but building a new paradigm for thinking about people, thought and reality", Sherry Turkle, "Second Self", 1984

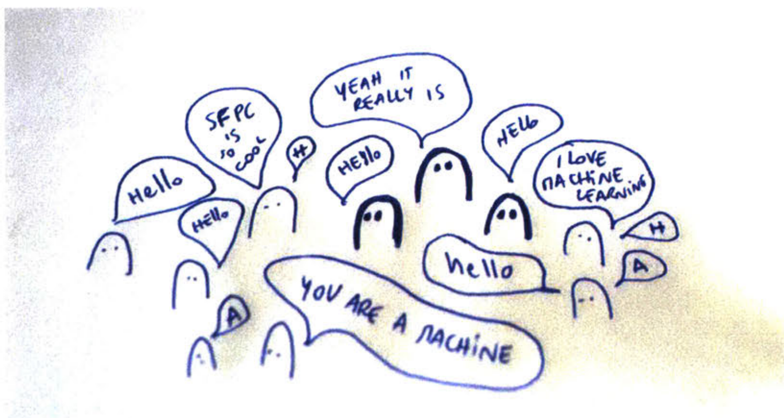


Figure 132: Drawing from Cognimates workshops with School of Poetic Computation Students in New York

Overall, we observed that children developed a rich grasp of AI concepts through play and coding with our platform. They also became more skeptical of the agents'smarts and truthfulness even if they continued to perceived them as friendly and exciting. International children were overall more critical of these technologies and less exposed to them. The way children collaborated and communicated played influenced significantly how far they were able to go in their learning and understanding of these new concepts. Children in low and medium SES schools and centers were better are collaborating initially but had a harder time advancing because they had less experience with coding and interacting with these technologies. Children in high SES schools and centers had troubles collaborating initially but overtime developed a strong understanding of AI concepts and started to teach and help each other

I recognize the following sets of challenges and opportunities for people interested in developing future devices or platforms for AI education:

- Avoid deceiving technologies, assume current state of the technology and involve participants in the process of developing it while making debugging intuitive and fun.

- Design systems where intelligence is associated more with decision making, gestalt, emergent schema and less with human imitation via a nice voice prosody.
- Put the child "in the agent shoes". Make the reasoning behind the machine as transparent as possible and give children opportunities for perspective taking, acknowledgment of different dimensions of mind perception.
- Provide various ways in which children could teach, customize and program the machine.
- Make the connection and shift between the physical and digital parts of your system obvious, allowing children to see when and if the machine is connecting to the cloud or which parts of it system it's using to detect what.
- Emphasize the importance of learning and provide meaningful feedback to children with each action they take so they see what the machine has learned or not.
- Encourage reflection and collaboration by allowing children to share and modify each other projects and models.

In future work I hope to be able to apply and refine these guidelines while continuing to learn from children and their AI inspired reflections.

12.1 SUMMARY CONTRIBUTIONS

- Overview of children and parents interactions with computational objects and review of current AI education technologies were presented in chapter 3 and chapter 4.
- Analysis of how children from different geographies and SES backgrounds interact with smart agents and change their perceptions after they learn how to program and train them in chapters: 6, 7, 8,9,10.
- Analysis of how children prior experience, social and cognitive scaffolding and collaboration skills impact the way they can program, train, understand and explain AI technologies in chapters: 6, 7, 8,9.
- First child-centered AI training platform (Cognimates Teach AI) is described in chapter 5.
- Design guidelines for an Artificial Intelligence (AI) education platform for children of 7 to 14 years old in chapter 5.

- Technical proposal for integrating cognitive services and DIY AI training into a visual programming language in chapter 5.
- Activity guides and teaching materials for AI education (Cognimates Learning Guides and starter projects) described in chapters 5 and 11, materials are made available in Appendix a.
- Evaluation metrics for children interaction, understanding and perception of AI technologies we refined and developed throughout all the long-term studies and are shared in Appendix a.
- Open-sourced design and code for a new AI education platform (Cognimates), all the code repositories are listed in in Appendix a.

I enjoyed working on the Cognimates platform because in a subtle yet powerful way it provides children with a glimpse behind the curtain of machine intelligence, and it stimulates them to think when and how to use this powerful tool as a means of playful exploration, personal expression, intellectual empathy.

In her book "Second Self", Sherry Turkle captures the core question that AI technologies bring to our society: "Debates about what computers can or cannot be made to do ignore what is most essential to AI as a a culture: not building machines but building a new paradigm for thinking about people, thought and reality (..)Whether or not AI can make robots with superhuman powers has material consequences of the first magnitude. But it is far away. What is here and now is the challenge of a new philosophy" (citation from "Second Self" book 1984, page 244)[64]. Reading these lines 34 years later we see how much AI has advanced to the point where more than 20 million children are growing up with smart assistants in their home and will probably take it as a given that you can talk to any device by the time they will be adults. The challenge of a new philosophy that Sherry poses still hasn't been resolved.

My numerous conversations with children, parents and teachers showed me that the time is ripe to engage them not only in the design of future AI applications but also in deep philosophical debate about why, how and when should these technologies become part of our children's lives.

From Syrian children in Berlin to the children in a summer camp in China or the children in a church community center in USA I saw how children can both take the smart devices at an interface level or engage with them in more creative and meaningful ways. As designers of technologies that support learning we are at an arms race with consumer applications that create and define trends of technology use for an entire generation . I hope this thesis will inspire other people to democratize access to AI education and invite children, parents and teachers to take part in this adventure.

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APPENDIX

A.1 AI PERCEPTION QUESTIONS

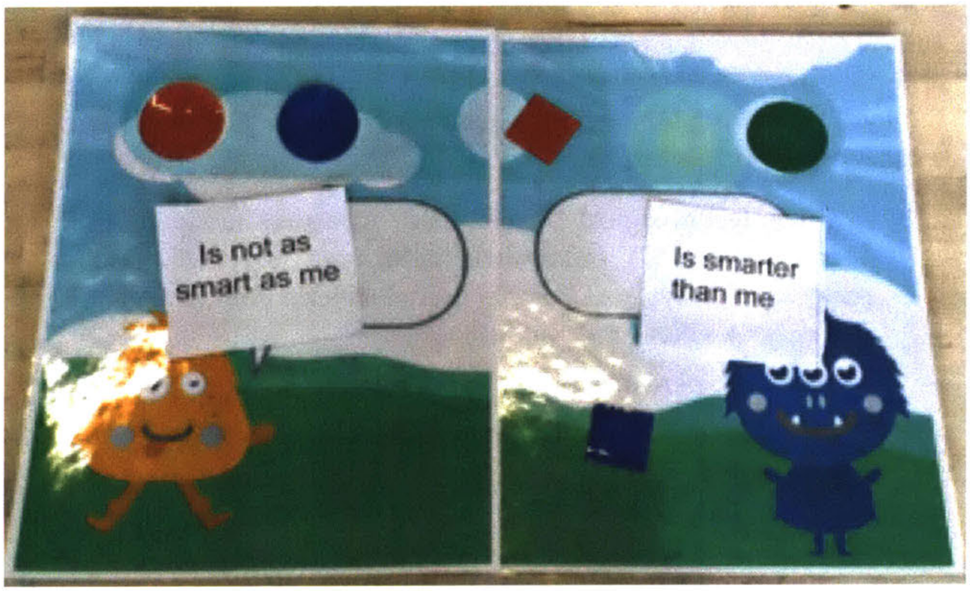

Figure 133: AI Perception Monster Game

During the first sessions of the long term and international studies students answered the following questions in the form of a monster game. I think the Agent :

- Is more like an animal - Is more like a person
- Understands me - Does not understand me
- Is unfriendly - Is nice friendly
- Is smarter than me - Is not as smart as me
- Likes/cares about me - Does not like/care about me
- Will remember me - Will not remember me
- Has feelings - Does not have feelings
- Will always tell the truth - will never tell the truth
- Made me feel bored - Made me feel excited

Adapted from Bartneck, Christoph, E. Croft, and D. Kulic. (2009) "Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots" In: *International journal of social robotic* (2009) pp. 71-81.

The printouts for the Monster sheets and the perception questions are available here: `http://bit.ly/cogni_printouts`.

A.2 VIDEO CODING SCHEME

All the sessions of children interacting with the agents, programming and presenting their projects were video recorded and coded according to the following scheme. Inter-rater conflicts were discussed until a consensus was reached.

1. Positive Technological Development measures (adapted from Marina Bears PDT framework (2008, 2012, 2017) [8], Coding scale: 5 - Always,4 - Often,3 - Sometimes,2 - Almost Never,1 - Never,N/A - Not Observable)
    - Prior experience
        - Evidence of child fluency of technology
        - Child level of experience coding
    - Communication skills
        - Child engages in two-way conversations
        - Child is warm and friendly with others
    - Collaboration skills
        - Child works together with other children on same project
        - Child seeks help from peers
    - Conduct
        - Child handles tools with care
        - Child shows respect to space
        - Child shows respect to peers
    - Presentation and demo skills
        - Child shares work with facilitators, teachers
        - Child shares work with peers
2. Collaboration type (adapted from Bruce B. Frey, Measure of collaboration scale [24])
    - 1. Networking (loose)
    - 2. Cooperation (formal)
    - 3. Coordination (shared info, some shared decision)
    - 4. Coalition (share ideas, resources)

  - 5. Collaboration (one system, mutual trust, consensus)

3. Type of conversation (adapted from Mercer (1995) [40], Wegerif and Mercer (1997, 2000) [70, 71], and Rojas-Drummond and Fernandez(2000) [55]).
   - Disputational talk: characterized by disagreements and individualized decision-making, and short assertions and counter-assertions.
   - Cumulative talk: speakers build positively but uncritically on what the other has said; it is characterized by repetitions, confirmations and elaborations and lastly
   - Exploratory talk: participants engage critically but constructively with each other's ideas, offering justifications and alternative hypotheses. Knowledge is made publicly accountable and reasoning is more visible in the talk, and progress results from the eventual agreements reached.
4. Higher-order cognitive and social skills (the definitions of cognitive and social scaffolding were adapted from Joolingen and Zacharias (2009) [32])
   - Cognitive scaffolding: child can identify the variables involved in a domain or task, generate testable hypotheses, design experiments to test their hypotheses and draw the right conclusion from experiments
   - Social scaffolding: child can facilitate collaboration and inquiry for others, map their ideas, visualize/demonstrate their differences etc
   - Content knowledge: child has a good grasp on the concepts required in the interaction/task
   - Process knowledge: child know how to structure work, break down a task, iterate, ask questions, find information, debug
5. New added measures
   - Perceived difficulty of the task (Coding scale: 3 - Easy, 2 - Medium, 1 - Hard)
   - How much time the child spends coding (3 - A lot,2 - Medium, 1 - Little, 0 - None, N/A - Not Observable)
   - Does the child change his opinion about AI (1 - Yes, 0 - No)

A.3 SENTIMENT ANALYSIS ON CHILDREN CONVERSATIONS

Listing below the libraries and tools used for performing sentiment analysis on children's conversations transcripts.

A.3.1 *AFINN*

The AFINN lexicon is a list of English terms manually rated for valence with an integer between -5 (negative) and +5 (positive) [43].

The original lexicon is distributed under the Open Database License (ODbL) v1.0. You are free to share, create works from, and adapt the lexicon, as long as you attribute the original lexicon in your work. If you adapt the lexicon, you must keep the adapted lexicon open and apply a similar license.

Sentiment analysis is performed by cross-checking the string tokens(words, emojis) with the AFINN list and getting their respective scores. The comparative score is simply: sum of each token / number of tokens.

Returned Objects:

-
- Score: Score calculated by adding the sentiment values of recongnized words.
- Comparative: Comparative score of the input string.
- Token: All the tokens like words or emojis found in the input string.
- Words: List of words from input string that were found in AFINN list.
- Positive: List of postive words in input string that were found in AFINN list.
- Negative: List of negative words in input string that were found in AFINN list.

Source: https://github.com/fnielsen/afinn

A.3.2 *Natural Language Toolkit (NLTK)*

NLTK is a leading platform for building Python programs to work with human language data. It provides and interfaces to over 50 corpora and lexical resources such as WordNet, along with a suite of text processing libraries for classification, tokenization, stemming, tagging, parsing, and semantic reasoning, wrappers for industrial-strength NLP libraries. For sentiment analysis neutrality is determined first, and sentiment polarity is determined second, but only if the text is not neutral [9].

Source: http://www.nltk.org/howto/sentiment.html

A.3.3 *TextBlob*

TextBlob is a Python (2 and 3) library for processing textual data. It provides a simple API for diving into common natural language processing (NLP) tasks such as part-of-speech tagging, noun phrase extraction, sentiment analysis, classification, translation, and more.

The sentiment property returns a named tuple of the form Sentiment(polarity, subjectivity). The polarity score is a float within the range [-1.0, 1.0]. The subjectivity is a float within the range [0.0, 1.0] where 0.0 is very objective and 1.0 is very subjective.

Source: `https://textblob.readthedocs.io/`

A.4 COGNIMATES STARTER PROJECT AND LEARNING GUIDES

All the code for the starter projects we used during the study are available here :`https://mitmedialab.github.io/cognimates-website/projects/`.

Learning guides are listed below.

A.5 COGNIMATES TEACHER MATERIALS

The teachers Master Guide:

- Master Guide for teachers: `http://bit.ly/Waterkinesis_MasterGuide`
- Lesson plan for the first day: `http://bit.ly/waterkinesis_Day1`
- Lesson plan for the second day: `http://bit.ly/Waterkinesis_Day2`
- Live demo code: `https://mitmedialab.github.io/cognimates-website/projects/waterkinesis`

A.6 TEACH AI

The "Teach AI" page of Cognimates where children created their own text and vision classifiers is available here: `http://cognimate.me:2635/`.

A.7 COMMERCIAL APPLICATIONS FOR EMBODIED INTELLIGENT AGENTS

During the initial sessions of interaction and perception of agents we used the following commercial applications:

- Anki's codelab for programming Cozmo robot: `https://www.anki.com/en-us/cozmo/code-lab`

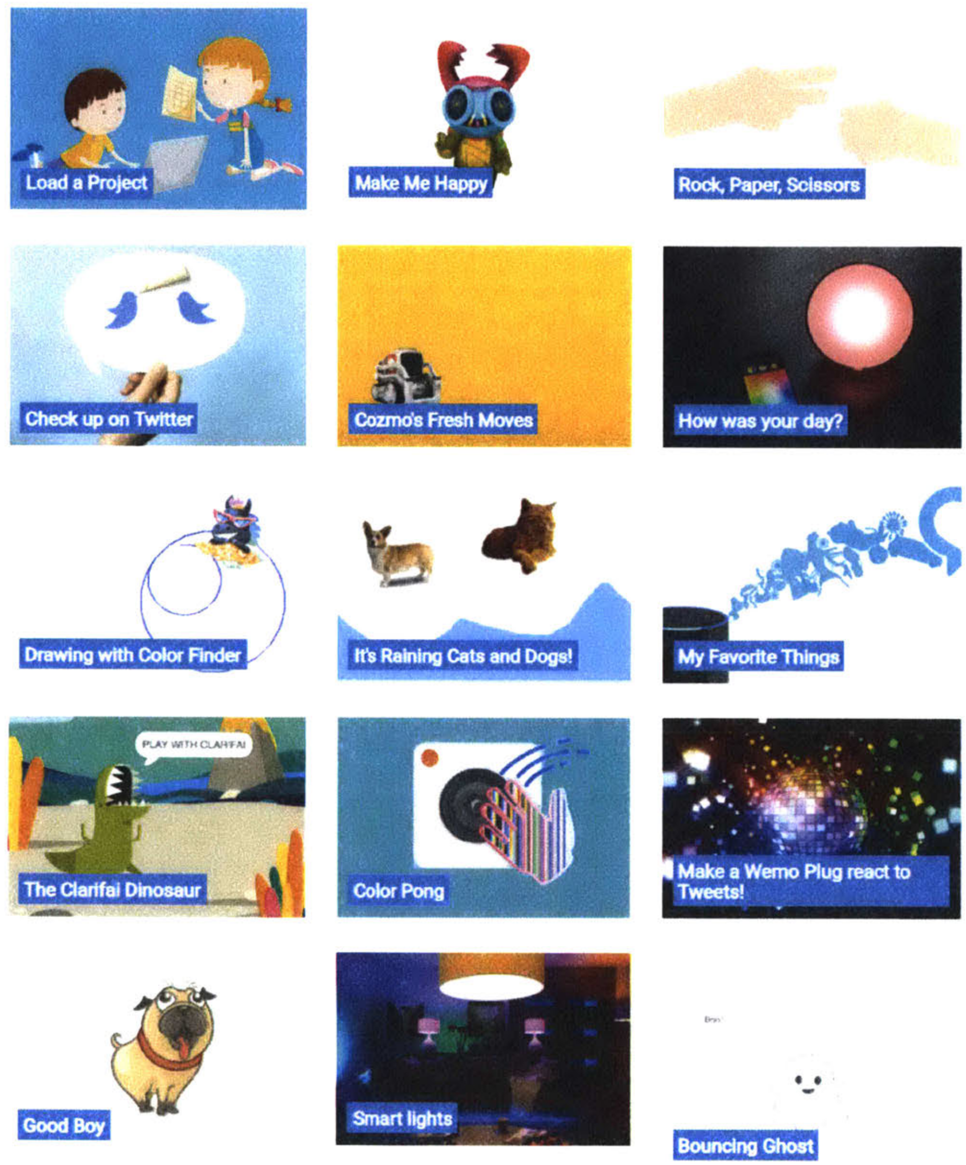

Figure 134: Examples of Cognimates starter projects used and modified by the students

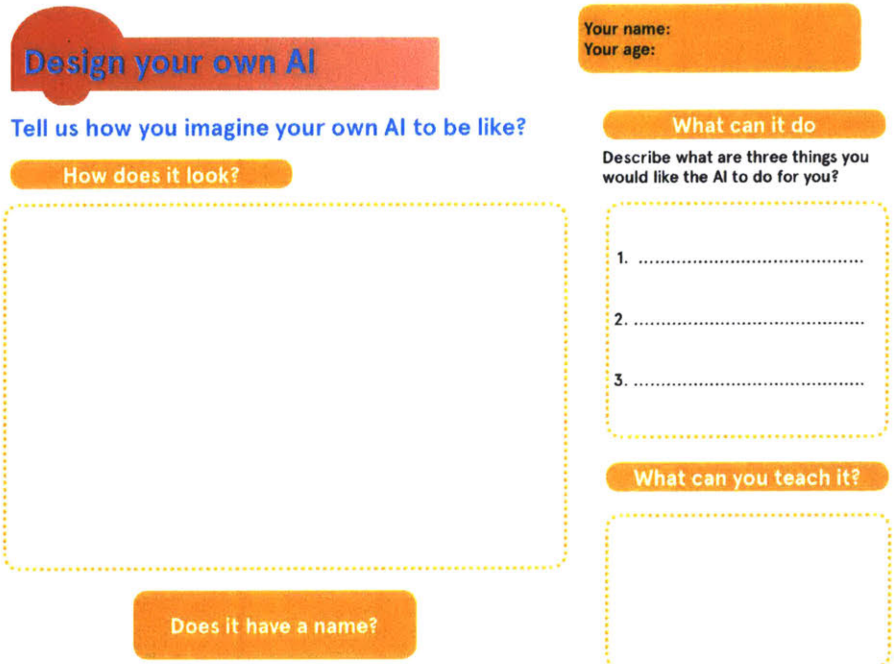

Figure 135: Design your own AI activity sheet

Figure 136: Make me happy activity guide

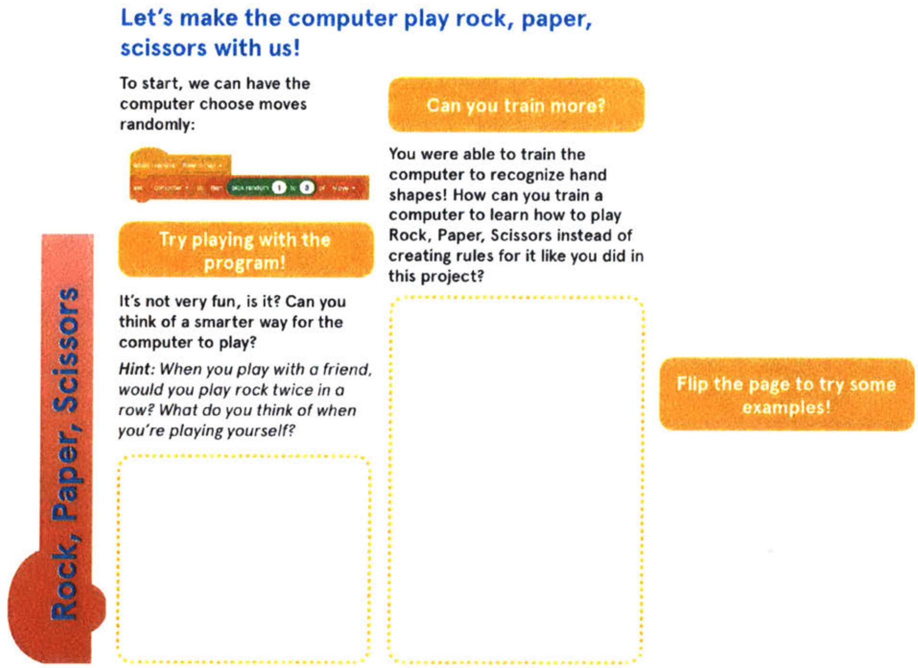

Figure 137: Rock Paper Scissors activity guide

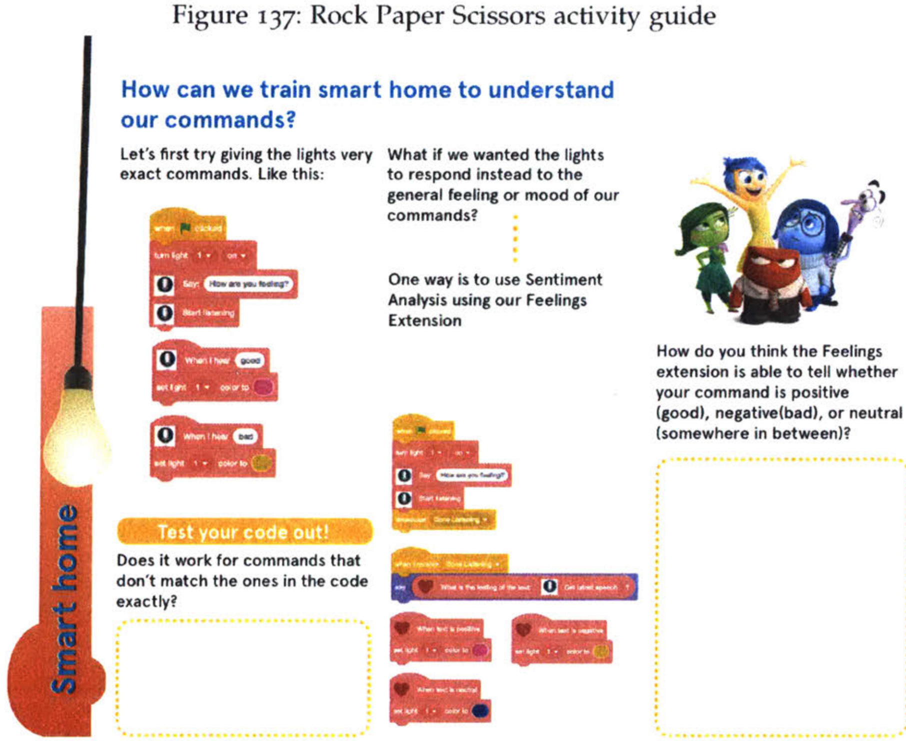

Figure 138: Smart Home activity guide

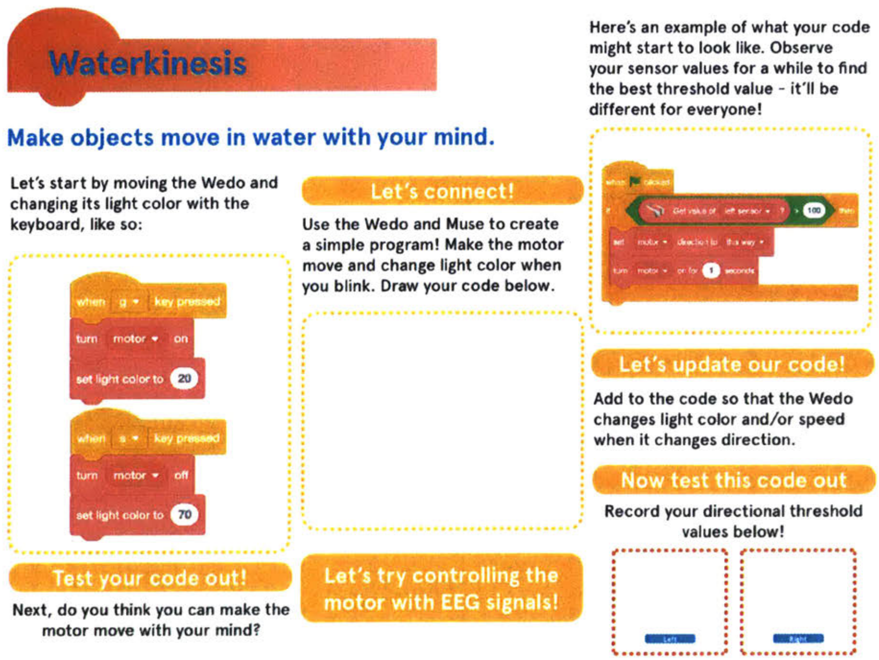

Figure 139: Waterkinesis activity guide

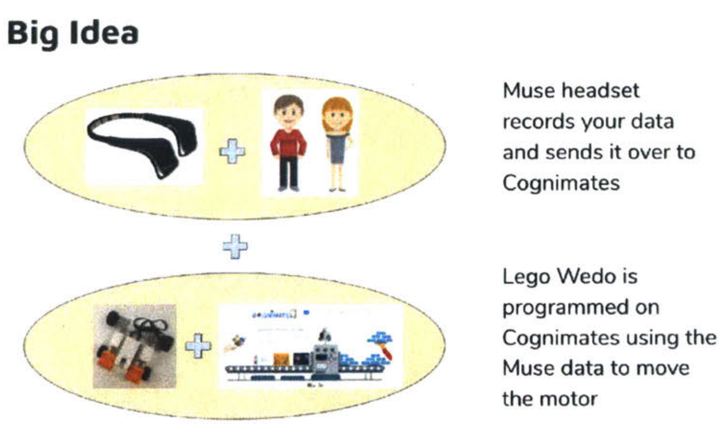

Figure 140: Waterkinesis Teacher Materials

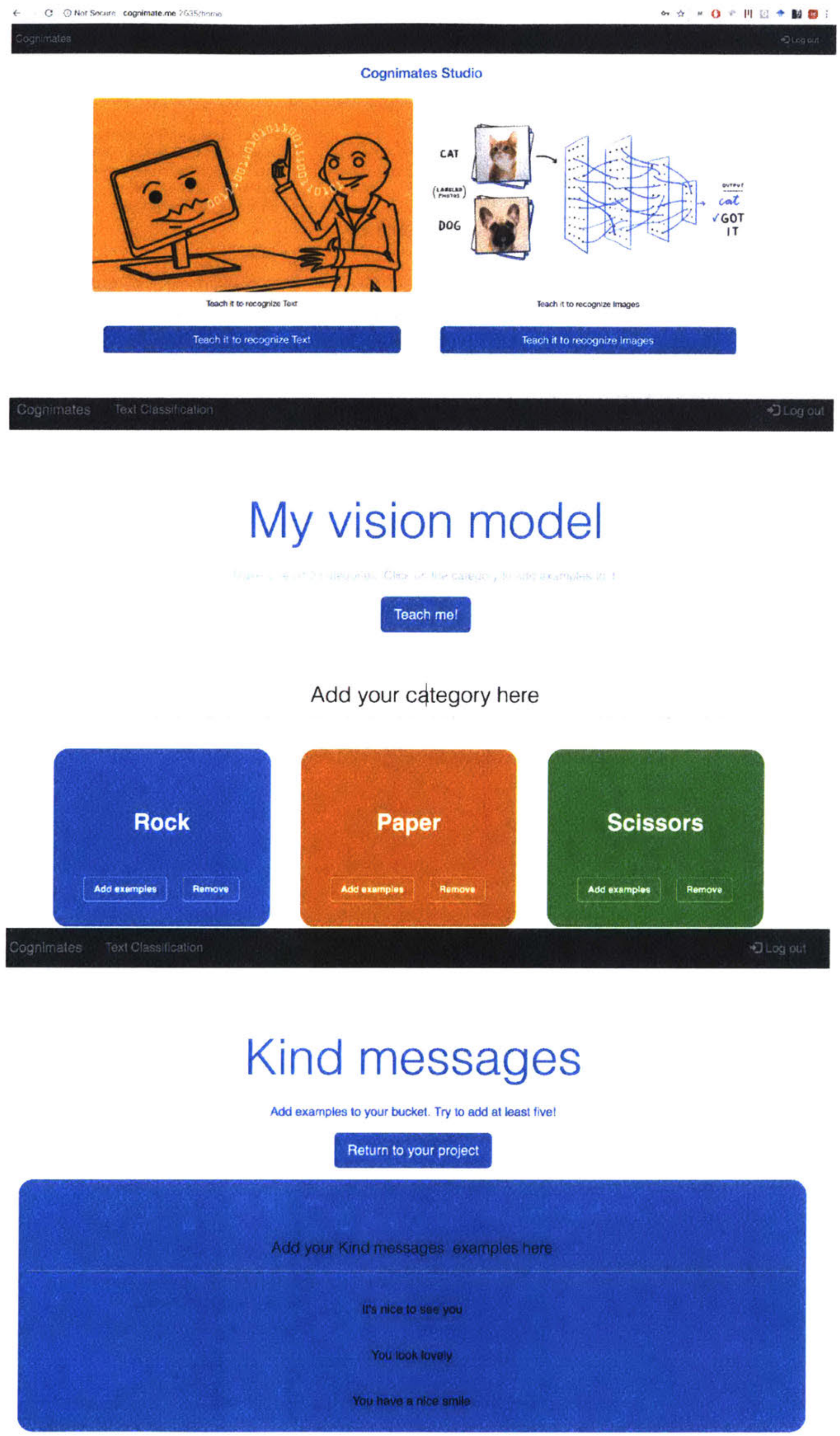

Figure 141: Caption

- BeAMaker mobile app for programming Jibo robot (also developed in part by the author of this thesis):http://beamaker.cloqq.com/

A.8 EXTERNAL APPLICATIONS FOR PLAYING WITH AI

During the study we also used the following applications to enable children to play and explore differen concepts of AI:

- Experiments with Google:
- https://experiments.withgoogle.com/collection/ai
- Quickdraw:
- https://quickdraw.withgoogle.com/
- Cleverbot:
- http://www.cleverbot.com/
- Sketching with Google:
- https://magenta.tensorflow.org/assets/sketch_rnn_demo/index.html

A.9 CODE REPOSITORIES

- Cognimates Virtual Machine :https://github.com/mitmedialab/cognimates-vm
- Cognimates Graphical User Interface: https://github.com/mitmedialab/cognimates-gui
- Teach AI page: https://github.com/eesh/watson_nlc_proxy
- Cognimates Alexa skill: https://github.com/eesh/Alexa_QnA_Skill

A.10 DEMO VIDEOS

- Demo Alexa Cognimates skill:bit.ly/cogni_alexaskill_demo
- Interviews at Shady-Hill:bit.ly/shaddy_cognimates
- Alice in wonderland project demo:https://vimeo.com/269095926
- Poppy Ergo Jr. extension demo:https://vimeo.com/218055021

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