Playful Learning in Robotics: A Case Study With Smart Motors Workshops

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***Abstract*—In this innovative practice paper, we present case studies of participants using a trainable robotics tool called Smart Motors from two workshops: one with participants from elementary schools in a robotics camp and the second with students from a high school. We designed the workshops to help us observe two key aspects: how students engage with the tool as new users from different age groups and the variability in levels of enjoyment and iterative thinking with an engineering design task while using the tool. Learning robotics can be complex as it can involve learning programming, mechanical design, and electrical circuits simultaneously. Some existing robotics kits support beginners with mechanical design tasks via easy-to-integrate sensor kits, motors, and control hubs, and some support beginners with alternative programming methods like web-based block coding languages and QR codes. However, cost, availability, and ease of use make integrating robotics into the curriculum difficult for some classes. Smart Motors are easy-to-use, low-cost alternatives to lower those barriers to bringing robotics into the classroom. Smart Motors simplifies mechanical "set-up" by packaging the user interface, motor, and sensor in one unit. They use training and a machine learning algorithm called the nearest neighbor to make decisions. Since they do not require coding to generate desired outcomes, students can use them in classrooms without computers or internet access. We allowed first-time Smart Motor users to learn the tool while participating in a play-based design activity with three sessions. The first session of the workshop was a discussion of Artificial Intelligence and Machine Learning. The second session was an introduction to Smart Motors, in which the participants built a "hello-world" waving contraption using Smart Motors and LEGO® pieces. The third session consisted of an activity derived from Tufts University's Novel Engineering curriculum, where the participants listened to a story, chose a character, and designed solutions for them. We analyzed their work with the help of field notes and video data. Using the Learning through Play Experience Tool, we looked for evidence of two of the five characteristics of playful learning: Joyful and Iterative. We transcribed the video data in detail and coded for the states of play in two-minute chunks, where we looked at and analyzed the play trends. We found that Smart Motors supports playful learning in engineering design workshops, allowing participants from different ages and experience levels to engage creatively to design products of various complexity.**

***Index Terms*—educational robotics, K-12, Case Study,**

I. Introduction and Background

There is plenty of evidence to show that educational robotics can support students' learning [1] [2] [3]. Integrating lessons with educational robotics can develop lifelong skills in students [4] [5] [6] [7] [8]. Due to the rapid development of technology more and more students can have access to these tools in their classrooms. However, there are still some challenges in providing access to robotics for everyone [9] [10]. First of all, integrating lessons with robotics can be challenging, especially for learners who are just getting started. Learning robotics involves learning to build mechanical designs, make electric circuits, and do computer coding simultaneously. This can unintentionally lead to frustration with the getting started experience and can develop negative attitudes toward learning the technology.

Some existing robotics kits like LEGO® Education SPIKE™ Prime[1] and LEGO® MINDSTORMS® EV3[2] have mechanical building system, along with neatly packaged sensors, motors, and control hubs, and some others support alternative programming methods like block-based languages [11] and QR codes (Kibo [12]). While these may be easy to use, they come with expensive price tags, [13]. There have been attempts to make such technology accessible for everyone with open-source hardware products like Arduino products[3] and open-source software products like Raspberry Pis[4]. Moreover, with the help of a community of users around these tools, learners can find resources to learn independently. However, these platforms can be cumbersome for beginners as they must learn to program and build electrical circuits simultaneously. These tools also require working computer systems that may not be available in all classrooms for all students [14].

Smart Motors, developed at Tufts CEEO [15], which costs under $30, can be an easy-to-use and affordable alternative to help learners get started with robotics. Since Smart Motors can be used without a computer, it can be used in any classroom - with or without computers and the Internet. They are easy to start, and users can build projects using LEGO® pieces or found materials. They use sensors to perceive the environment (sense) and onboard computers that can process the information (think) to give the motors to manipulate the environment

[1] https://education.lego.com/en-us/start/spike-prime
[2] https://www.lego.com/en-us/product/lego-mindstorms-ev3-31313
[3] https://www.arduino.cc
[4] https://www.raspberrypi.com

(act), providing an authentic robotics education experience [16]. By integrating Smart Motors with a playful learning approach, we can create a meaningful learning experience for learners.

A. Playful learning with technology

Learning through play has garnered much interest in both early childhood and adult education [17] [18] [19]. Evidence suggests that play effectively facilitates learning across diverse learner profiles [20] [21] [22]. This approach resonates with learners of all ages as it harnesses innate human qualities such as curiosity and creativity. In a playful learning approach, learners engage in intrinsically motivated activities, allowing them to explore, experiment, and build and enhance their knowledge through self-reflection [23]. This learning style supports the development of 21st-century skills like creativity, collaboration, communication, and critical thinking [24].

Educators have employed different play styles- from open, self-directed play to more constrained designed challenges [25]. Despite the nature of play involved, playful learning immerses learners in the activity where they experience and find personal meaning. Similarly, the materials used in playful learning approaches vary greatly, too. These materials range from everyday objects (found materials) to computers and are used to teach topics related to literacy, history, and STEM [26] [27] [28]. Using a playful learning approach to technology was pioneered by Papert in the 60s [29]. He engaged learners in learning programming by interacting with the programming language, Logo, in a playful, self-directed way. Educators have developed different ways of introducing and teaching technology in their classrooms. Scratch[5], a block-based programming paradigm, is used by thousands of learners every day to create games and stories that are meaningful to them and learn computational thinking in that process. While the type of play and content varies greatly, the essence of playful learning remains constant throughout the different contexts - to allow self-directed learning through personally valuable explorations.

B. Smart Motors

Smart Motors are pre-programmed motors that can be trained to respond to different sensor inputs. Shifting the focus from coding to training robots increases accessibility to robotics for students in several key ways [30]. It consists of a microcontroller for processing; a motor as an actuator; a small screen, knob, and buttons as a user interface; and supports a range of analog sensors for control or input. Users operate the tool with the onboard knob and buttons to train the motor and change between modes (Figure. 1). A small screen provides information about the states and modes of the tool. Publicly available design of Smart Motors and instructions can be used to build Smart Motors for the price of about $30. Using the pre-built design files and instructions, educators can order the circuit board from a PCB manufacturing company,

[5] https://scratch.mit.edu

Fig. 1: Smart Motor showing *Training* and *Playing* icons on the screen. The potentiometer, next to the screen, sets the servo motor's position on the top face. The select button below the potentiometer takes user inputs. Two navigation buttons on the left face let the user interact with the UI. The sensor is connected to the port on the right face. The other sides have LEGO® compatible holes to build with LEGO® bricks.

and the enclosures can be 3D printed on a regular 3D printer. Other peripherals like servo motors and batteries can be purchased locally. Depending on the type of servo motor (discrete or continuous), it can be either a position-control Smart Motor(SM1) or a speed-control Smart Motor (SM2).

The version of Smart Motors used in the workshops described in the paper runs a simple machine-learning algorithm called nearest neighbor. Nearest neighbor [31] is a fundamental machine learning algorithm that does not require large datasets. This algorithm suits cases where the training dataset is smaller, and we want to build our training datasets. Users can use this algorithm to train the motors to specific locations based on the closest training datum to a sensor reading. There are two steps involved in using Smart Motors: training and playing. Playing is the mode where the Smart Motor uses the Nearest Neighbor algorithm and the training data to determine its output location.

1) Training: To train, users move the motor to a position or run the motor at a speed in the direction of their choice by using the built-in potentiometer (knob). They place the sensor in a position in the user's environment such that the sensor's reading can uniquely link to the motor's output. Training data is collected when users press the select button. This creates a pairing of a sensor reading and the motor position or speed. Users can create multiple pairings in this step.

2) Playing: Users put the Smart Motors into playing mode to execute the training data. In this mode, the algorithm determines the position of the motor or its speed by comparing the current sensor reading with the other sensor readings in the training dataset. The Smart Motor chooses the closest motor position or speed using the nearest neighbor algorithm and moves the motor to that position or runs the motor at that speed.

II. Methodology

We designed a three-session play-based activity to introduce and implement Smart Motors. We implemented those activities in two workshops, W1 and W2. Twelve fourth through sixth graders participated in W1, and ten high school seniors participated in W2. Both workshops were led by educators with extensive experience in formal and informal education settings. W1 was run as a part of a larger robotics camp at a local makerspace in New Hampshire. The participants from the camp voluntarily participated in the workshop, and data were collected from 11 consenting participants. W2 was run in a Chemistry and Physics Projects for Seniors (CAPPS) course in a high school in New Hampshire, and 9 of them consented to data collection.

A. Research questions

For this study, we set out to answer two questions.

1) How do students of different age groups engage with Smart Motors in a play-based activity?
2) Using the Learning Through Play Experience Tool developed by The LEGO Foundation [32], can we find evidence that Smart Motors facilitates playful learning?

B. Workshop design

There were three sessions in both workshops. The instructors discussed Artificial Intelligence (AI) and Machine Learning (ML) in the first session. They engaged the participants in a discussion through pictures of different animals and how they could discern between them. They reflected on and drew similarities between how humans categorize objects in everyday life using pre-existing knowledge of patterns and other characteristics and how machines categorize objects by learning from vast amounts of data. Through this discussion, the instructors introduced the concept of data and training a machine using algorithms rather than coding to create a desired outcome.

The second session was to learn using Smart Motors through demonstration and practice. To make it a playful exercise, they were asked to design and build a 'Hello World' waving mechanism with LEGO® pieces and a Smart Motor and make it wave by manipulating the sensors. The session began with a presentation showing the features of Smart Motors and a short demonstration of how to use them. All participants were given a Smart Motor to train and build the mechanism. They were allowed to combine their individual mechanism to build a larger waving structure.

The third and final session was a Novel Engineering activity where they listened to a short story called *Muncha! Muncha! Muncha!* by Candace Fleming. The Novel Engineering framework for engineering design entails reading a story as a group, discussing the issues and challenges the characters face in the story, and designing solutions for the characters they connect with [28]. The participants worked in groups to create solutions for either Mr. McGreely, the farmer troubled by bunnies stealing vegetables from his garden, or the bunnies who were hungry and stole the vegetables from Mr. McGreely.

1) Differences in two workshops: While the two workshops had the same content and were run using the same playful approach, there were some differences. The workshop was run with two different age groups of students. W1 was run with elementary students (fourth through sixth graders), and W2 was run with high school seniors. The Smart Motor code used in W1 had features to save and retrieve training data. While it allowed users to save multiple training data, it added a layer of complexity to the user interface (UI). The firmware was updated for W2 to make the UI more simplistic. Another difference was the duration of the activity. Since W1 was part of a camp, we could run the sessions longer. W2 was run during class hours in a high school, so we were limited in time. Both sessions one and session two in W1 ran for one hour. In W2, session 2 ran 30 minutes, and session 3 ran 45 minutes. In addition, participants in W1 used position control (SM1 type) Smart Motors, while participants in W2 used both position control (SM1 type) and speed control (SM2 type) Smart Motors.

C. Data Collection

All the sessions were video and audio recorded. Cameras and microphones were set up at each desk to capture the group discussion and activities. Transcripts were generated from the discussion in all three sessions. In addition, researchers took field notes during the workshops.

D. Data Analysis

To answer the research questions for this paper, we analyzed the data from session 2 in both W1 and W2. Grounded theory [33] was used to analyze the data to answer the question related to engagement with Smart Motors. The data were transcribed and coded for themes. The transcription and description of data were used to identify moments where participants made discoveries and showed signs of neutral, curiosity, enjoyment, sense of accomplishment, and enthusiasm. This information was used to compare between the two groups.

To look for the evidence of playful experience, we used the Learning through Play Experience Tool developed by The LEGO Foundation [32]. All video data from session two were transcribed in two-minute chunks for each participant. For each two-minute section of the activities, the data was coded into one of the seven states of play for characteristics of playful learning. The Joyful and Iterative characteristics of play were chosen for coding. We decided to code for Joyful characteristics because joy, in addition to being one of the characteristics of play, is intrinsically connected with learning [34] [35]. We chose iterative because iteration is one of the characteristics of the engineering design process we were interested in. The states of play given by the experience tool are Non-Play, Waiting, Passive, Exploring, Owning, Recognizing, and Transferring. Rubric from the learning-through-play experience tool (Table I) was used to code the data. In the

TABLE I: JOYFUL AND ITERATIVE CHARACTERISTICS' RUBRICS FROM LEARNING THROUGH PLAY EXPERIENCE TOOL

State of play	**Joyful**	**Iterative**
No Observation	No opportunity to observe this characteristic	
Non Play	I am opting out of the experience	
Waiting	I am waiting my turn	
	I am waiting for resources	
Passive *I am following instructions*	I am neutral about the experience *Leo passively plays with the trained motor*	I do not know how to respond to the experience *Keshav doesn't engage with the activity towards the end of the workshop*
Exploring *I am considering possibilities*	I am curious about the experience *Ben gets curious about the motor and starts exploring*	I interact with the experience *Jason attaches the arm to the motor and trains it with 3 data points.*
Owning *I am choosing my own paths*	I am enjoying the process, even if it's challenging *For some reason the head doesn't attach, but Ben is persistent*	I adjust my approach *Tim takes multiple data points for small changes in light sensor to make the arm move fast.*
Recognising *I have new insights*	I feel a sense of accomplishment *Leo shows his partner the hand he built, visibly proud of his creation.*	I am deliberate about the changes I make *Jason starts redesigning the arm from scratch with his experience from the previous arm design.*
Transferring *I am reflecting on how this experience can influence the reality of my own life, and have confidence that it changes myself and others*	I am enthusiastic about trying this again	I seek out and explore new projects

end, the trends of states of play were studied. The participants' tone and body language were taken into account while coding.

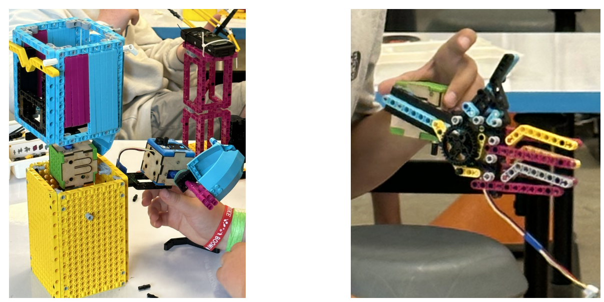
III. Description of Cases

We chose two participants, Ben and Leo (pseudonyms), from workshop 1 (W1) and three participants, Tim, Jason, and Keshav (pseudonyms), from workshop 2 (W2), for analysis. Ben and Leo worked independently in two groups and were mainly visible on camera, making data transcription possible for the whole session. In contrast, Tim, Jason, and Keshav were part of the same group and worked independently.

A. Case 1: Ben and Leo

Ben and Leo were part of groups 3 and 4, respectively. They approached the problem differently. While Ben took a leadership role in his group, steering the project, Leo worked alone from the beginning, occasionally interacting with his partner to ask questions about operating the Smart Motor.

Ben started by asking his instructor, "How do you tell the motor to do something?" The instructor told him to press the big button until the square turned solid (indicating data was stored). He took data in two extremes - the motor turned to zero degrees as a minimum position for the wholly covered light sensor condition, and the motor turned to a maximum of 180 degrees for the uncovered light sensor reading ambient light value. Ben said, "My motor is not turning," after realizing the motor was not moving when he covered or uncovered the sensor. An assistant suggested that his Smart Motor might still be in training mode and helped him enter Playing mode. Upon noticing the motor was still not moving, Ben wondered, "The motor might be jammed," and asked for a replacement. He trained the replacement motor, which moved the way he expected.



(a) Humanoid built by Ben and his team.

(b) Leo's hand built using LEGO® pieces.

Fig. 2: Projects built by Ben and Leo.

Once Ben trained the motors to two extreme positions for two extreme light sensor values, he confirmed that other participants from the group wanted to work together as a team. He convinced them to follow the same training regime. Within about four minutes, he had learned to use the Smart Motor, got the team ready to build, and started building the mechanism.

Ben and his team worked on building a humanoid with a gesticulating head and arms (Figure. 2a). Ben worked on the head and assigned his teammates the task of building the body and arm. The team members worked independently to build their assigned parts. Ben helped his teammates train their motors and occasionally checked how they were progressing. The head (Figure. 2a) had details such as moving hair strands made out of LEGO® beams as well as eyebrows and a mouth. Ben spent much time building the interface between the head and body, allowing them to attach easily and securely. Ultimately, he trained his head to move to three positions based on three different light conditions.

On the other hand, Leo spent the first 10 minutes trying to figure out how to use the Smart Motor independently. He moved the motor with the potentiometer, checked how the light sensor moved the dots on the screen, and pressed the buttons. However, he could not train the motor. Leo had seen his teammate getting help from an assistant earlier. So, after exploring for a while, he asked his teammate for help. The teammate showed Leo how to train the motor and trained the motor for him.

Leo started by adding LEGO® pieces to the Smart Motor, testing how they moved with the changing light sensor at each step. He eventually decided to build a detailed representation of a hand with all five digits of appropriate lengths. For that, he spent significant time finding and connecting the right pieces, often comparing them with his own hand for reference. At first, he built a palm-like structure with a slight curve in the middle. "Now I can add you to your fingers," Ben said to his LEGO® palm. He tried beams of different lengths and colors to get the right shape. "Oh my gosh.. this is a perfect hand!" he exclaimed, after getting the desired outcome after many iterations! Unfortunately for Leo, he lost the training data his teammate helped with because he turned off his motor while he stepped out for a break. When he returned, Leo continued working on completing his hand, adding features for the wrist. When he realized his motor was not responding to the light sensor, he tried to train it again, but it did not work. He hesitantly asked his teammate for help to train it to extremes. Interestingly, the teammate who had previously trained Leo's motor struggled to run it. Leo recognized and informed that he was in the wrong mode. Leo let the partner train his motor while he continued working on his model LEGO® arm. Towards the end, he found that the motor was not moving, which he suspected was because he had taken "too much data". Leo reset the motor and trained on his own to rectify this error. After fiddling with it for a while, he got the motor working. He attached his LEGO® arm, but it was too heavy for the motor to lift. To minimize the load on the motor and fix the issue, he made the LEGO® arm move in a horizontal plane.

B. Case 2: Tim, Jason, and Keshav

Tim, Jason, and Keshav were in the same group and followed similar paths. It was evident during the beginning of session two that all three learned how to operate the Smart Motor from the workshop instructor's demonstration. Without assistance, the whole group trained and tested their Smart Motors before moving on to the 'Hello World' waving activity. They all started with a simple waving mechanism before trying out more creative ideas with the position-controlled type or SM1-type Smart Motor. They were building with shared pieces from a single LEGO® SPIKE Prime Kit. During the build, there are a couple of key moments. About 15 minutes into the 30-minute activity, an assistant asked the group how they were doing. Keshav remarked, representing the perspective of the whole group, "Is this all we need to do?". The assistant told them they could use speed-control or SM2-type Smart Motor in their designs.

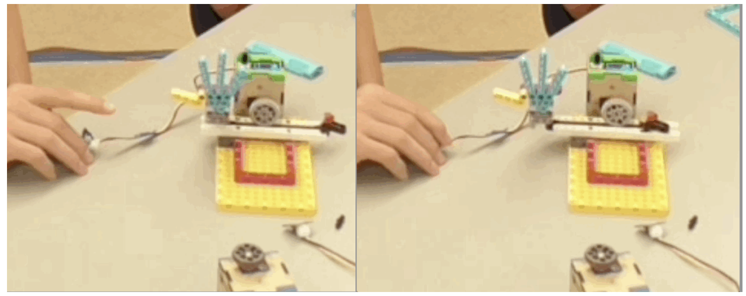


Fig. 3: Tim's waving mechanism with a sliding beam under the motor wheel.

Tim started by attaching the LEGO® pieces to the Smart Motor. Because he started building immediately, he could find all the pieces he needed. Tim began by building a hand with five digits. When his teammates complained of a lack of pieces to build with, he said, "I think making a good-looking arm is not the goal of the activity" and urged his teammates to be "innovative" as he took pieces apart from his build for them to share and modified his arm to have three digits. He experimented with how he would trigger the light sensor. He shared with his group that he wanted the arm to wave at him as he waved at it. So, he placed the light sensor on the table and trained the motor to move to one position when the hand was directly over the sensor and to another when the hand was away. Because the motor was trained for two sensor readings, it would not move sometimes as it would miss the sensor reading. He examined the situation and retrained the motor to move from one extreme to the other for multiple positions of his hand in front of the sensor. That way, the arm waved multiple times as he brought his hand closer to the sensor.

Next, Tim experimented with the speed control Smart Motor (SM2). He found that he could control the speed and direction of the motor. He said he wanted the arm to wave side-to-side instead of turning around a pivot (the previous build). He built a rack and pinion style mechanism with a beam sliding under the wheel and mounted his arm on the beam to accomplish this new goal. He played around with different pieces and orientations to get the wheel touching the beam just enough to make it slide. With about four minutes left before the end of the activity, Tim was still finishing his build and had yet to train the motor. He quickly trained the motor just in time for the demonstration.

At the beginning of the 'Hello World' waving part of session 2, Jason said, "I want to make it so complicated.". He did not want a simple left-right waving motion. He wanted his mechanism to wave by repetitively curling four fingers down and then opening back. However, he started his exploration with a simple build. He took his time to choose the pieces and attach them in a particular order to build the arm, connect it to the Smart Motor, and train it. The arm moved left and right, as

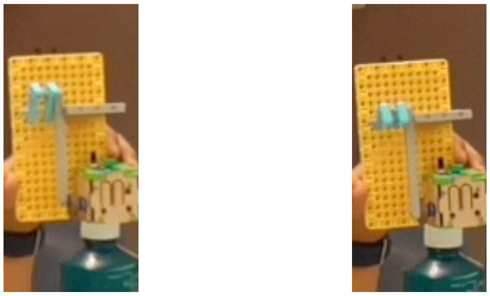


Fig. 4: Jason's waving hand using a continuous motor.

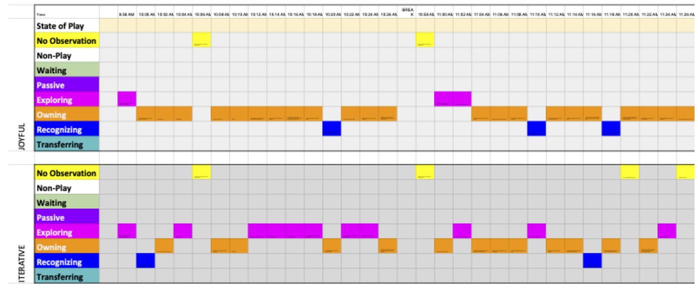


Fig. 6: Ben's trend of play in session 2 shows exploring and owning states alternative for joyful, and sustained periods of exploring state for iterative characteristics of play.

expected. He looked at his design, smiled, and said, "It needs to look a little bit, not horrendous.". He said that he wanted to build his original design. Keshav was not paying attention, but Jason persisted. He told Keshav again that he wanted to build his original design. Finally, Keshav responded. He said, "Yes, but it is hard to do".

Unlike Tim, Jason did not immediately start exploring SM2 with its continuous rotation when the assistant suggested it. He finished his first build, trained it to go to three different positions, played it for his teammates, and then started exploring the SM2 motors. They were approximately 20 minutes into the activity and had 10 minutes remaining. Jason left his earlier mechanism intact if his explorations did not work out. Again, like the first build, Jason carefully chose the pieces he wanted to use. With two minutes remaining, he completed his build and turned the motor on. His build was based on a cam mechanism. The wheels, when turned, moved a beam up and down. The hand's "fingers" were attached to this beam and moved as Jason originally envisioned. Jason did not train his motor but controlled the speed with the potentiometer, which worked like an automaton.

Keshav followed a similar trend as Tim and Jason - building a simple waving mechanism and training it with a type motor. However, little time was left when he decided to explore with the SM2. Different from Tim and Jason, Keshav chose not to explore further. Keshav spent the first few minutes brainstorming and exploring the LEGO® pieces. Like Jason, he had to use the leftover pieces from Tim initially. Keshav's arm was simple in design - it had a wrist and three fingers. When Jason commented, "cute", Keshav responded, "Hey, it gets the job done". Keshav attached the arm to the motor and moved it with the potentiometer to test how it moved. Jason commented that the jerky movements of the motors were "unappealing". Keshav defended the movements as "robot-like". He added more LEGO® pieces to his arm and told Jason, "Look, it looks pretty handish.". Keshav then trained the motor to go to two positions for two light sensor readings. He placed his finger over the light sensor to test whether the motor worked.

Fig. 5: Keshav's waving arm trained for two positions.

When the assistant came to check in and told them they could use a different motor, Keshav was the first to figure out that it was speed-based. He noticed the motors were strong enough to pull the rubber bands for, presumably, a different project. Tim and Jason used the two available SM2 motors, so Keshav started experimenting with some gears. He mounted them at 90 degrees to build a right-angled transmission. He didn't complete the build, but it looked like he was trying to improvise a new waving mechanism. When the instructor informed them they had four minutes remaining, Keshav stopped his exploration of the gears, reconnected his arm to the motor, tested it, and got ready for sharing.

IV. Results

Using the rubric from Learning through Play Experience Tool (Table. I) the data were coded for the five participants. Example observations used for coding the data are given in the table. In the figures showing the trend of play, each box represents a two-minute segment of the data, and the highlighted box indicates the most prominent state of play in that segment. The top and bottom half of the figures show the states of play for Joyful and Iterative characteristics, respectively.

Analyzing the play trends from the figures, we can observe how the participants moved across the states at different project stages. We noticed the participants operated more frequently in the Exploring and Owning states than others. There weren't many observations in the Passive state in both cases.

A. *Joyful states of play*

For Joyful, we noticed Ben and Leo from W1 started at the Exploring state. Ben (Figure. 6) quickly transitioned into the Owning state as he decided early on what he and his team would build. He stayed at the Owning state for the most part, transitioning to the Recognizing state a couple of times when he had something built that the instructor or other participants praised. Leo (Figure 7) spent the first few minutes in the Exploring state, where he explored Smart Motors and the other materials to understand what was possible. Once set on his project idea, he moved to the Owning state and stayed focused despite the challenges. He exhibited happiness and pride at how well he built his arm and moved to the Recognizing state.

We also noticed similar trends in the case of Tim, Jason, and Keshav from W2. They all started at the Exploring state, transitioned to the Owning state, and had a moment of Recognizing at various times before returning to the Exploring and Owning state. They started by building something simple, and when it worked, they explored and dedicated their time to building something complex. In the case of Tim and Jason (Figure. 8 and Figure. 9), they had a second moment of Recognizing while Keshav (Figure. 10) went from Exploring to Passive when he heard the instructor announce that there were only 4-minutes-remaining for building. Unlike Tim and Jason, who stayed in the Owning state to complete the build, Keshav went to the Passive state with his waving arm built to wait for his time to showcase his build.

B. *Iterative states of play*

For Iterative, the trends were not as predictable as for Joyful and it depended on the participants' building style - planning ahead vs experimenting as well as the complexity of the design. Looking at Ben's trend of play (Figure. 6), we can see how he explored first, noticed something not working, and used that knowledge to figure out the changes to make in the build. He had two moments of Recognizing when he realized simple adjustments to the design would not be sufficient to fix the problem he had - first, when he knew he had a broken motor that needed replacement and second, when he found that his training would not work for the orientation of the head and body, so he had to clear the data and retrain the motor. Leo (Figure. 7) had sustained periods of Exploring and Owning. This was because Leo's project involved fewer parts and most of his iterations were on the same section of the project. Leo's major iterations were when he started to make the fingers look

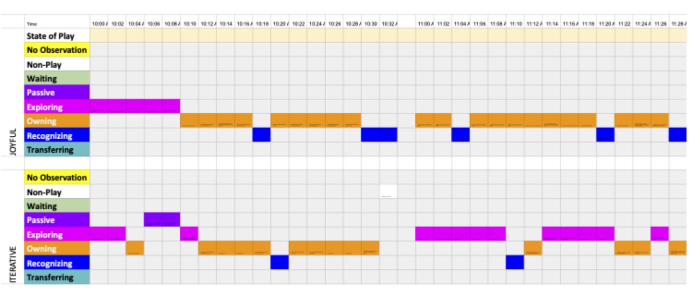


Fig. 7: Leo's trend of play in session 2 shows exploring and owning states alternative for joyful, and sustained periods of exploring state for iterative characteristics of play.

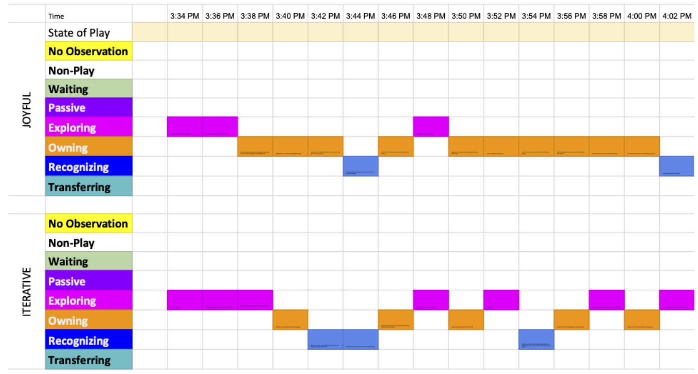


Fig. 8: Tim's trend of play in session 2 shows sustained periods at owning for joyful, and transitioning states between exploring and owning for iterative characteristics of play.

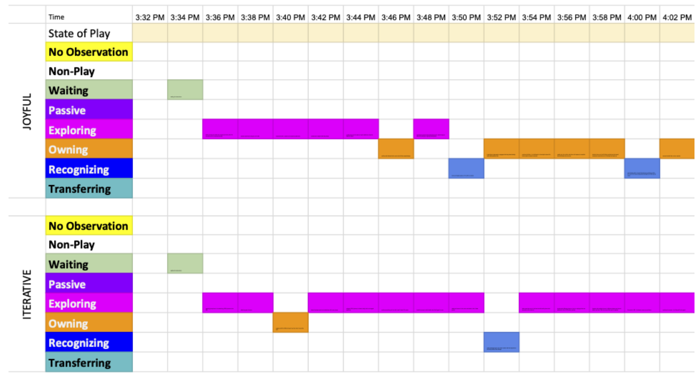


Fig. 9: Jason's trend of play in session 2 shows first half of exploring and second half of owing for joyful, and mostly exploring state for iterative characteristics of play.

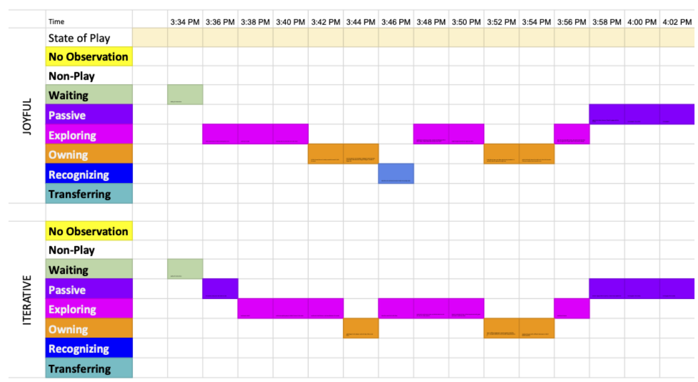


Fig. 10: Keshav's trend of play in session 2 shows alternating exploring and owning states of the joyful characteristic of play, and sustained periods of the exploring state for iterative characteristic of play.

realistic and tried to build a strap to hold the arm as it was unstable.

In the case of Tim, Jason, and Keshav, Tim had the most iterative transitions, followed by Keshav and then Jason. Tim's build style was to explore a piece, attach it, quickly decide if it worked or not, and move on to another piece. Keshav and Jason spent much time in Exploring, looking for available pieces they could use. In the case of Jason, he gave what he wanted for his design a lot of thought before trying it. We noticed Tim had a couple of major iterations, like when he decided the arm was not moving fast enough. He had to retrain the data in a completely different way, and when he realized that his mount had spacing issues causing the beam and wheel to slip so he decided to use a different method.

V. Discussion

A. Using the Learning Through Play Experience Tool, can we find evidence that Smart Motors facilitates playful learning?

The Learning through Play Experience Tool suggests that the goal for the participants is not to reach the deepest levels as fast as possible (cite white paper). This is consistent with our observation. Our data analysis shows the deeper states of play can be achieved by first reaching and experiencing the shallower states. Our observation shows that the participants do not stay in the deeper states of play for a prolonged duration and shift back to shallower states to generate and experiment with more ideas from the insights developed at the deeper states.

The analysis of two of the five characteristics of play shows that Smart Motors workshops provided a playful learning opportunity for the participants. The participants moved through different states of play during the session. The recurring pattern we observed was that they entered the experience by considering many solution paths through exploration. After exploring the possibilities, they formed an idea and dipped into the Owning state ("I am choosing my own paths") until dipping further to the Recognizing state of play ("I have new insights"). We observed some students follow this trajectory several times throughout the workshop. Others exhibited this trend throughout the whole workshop.

We observed that almost none of the participants entered the Passive state, except for one towards the closing portion of the session. His passivity could be explained by the lack of the remaining time and the functioning state of his project. The lack of Passive moments in the earlier and middle stages shows the participants were all engaged with the activity. Furthermore, we also didn't observe participants entering the Transferring state (*"I am reflecting on how this experience can influence the reality of my own life, and have confidence that it changes myself and others"*) The Transferring state may require multiple sessions to reach such depths.

Overall, despite the difference in age and length of the workshops, we observed similar patterns consistent with the playful learning approach when looking at the play trends.

B. How do students of different age groups engage with Smart Motors in a play-based activity?

Regardless of age, both sets of participants learned to train their Smart Motors and successfully used them in their projects with various levels of sophistication. The diversity of solutions in those projects shows independent thinking and creativity in the participants within the open and non-restrictive nature of the workshop with Smart Motors.

While the results of both sets of participants yielded a diversity of solutions through Joyful and Iterative play, the younger participants required a little more instruction beyond a brief demonstration to learn how to use Smart Motors. The younger participants learned how to use Smart Motors by asking questions of their peers and through deeper explorations. After watching a demonstration, the older participants had no trouble learning to use Smart Motors. Their knowledge of training and use of one type of Smart Motor (SM1) transferred to using a different kind of motor (SM2) with no additional direct instruction.

All five participants presented in this paper represent different design paths. From a Smart Motor as a robotics tool perspective and utilizing a playful learning approach, all students were afforded the opportunity to pick their learning path. Ben could use the Smart Motor as a part of his exploring. He understood how to train it early and perhaps that gave him the "freedom" to focus on building. Leo focused on the build first and then learned to train the motor "just in time" for the final exhibition. Perhaps Leo observed that training the motor for the desired outcome would not take long, giving him the chance to spend time perfecting the model of his hand.

Tim, Jason and Keshav learned to use the Smart Motor during the short demonstration which allowed them to start by exploring the mechanisms and achieving the desired outcome in a short amount of time. Tim's decision to take the risk of redesigning his project with only a couple of minutes remaining showed his confidence in himself and his trust in Smart Motors' ability to be quickly trained with the appropriate level of accuracy. Similarly, Jason's use of the Smart Motor's feature that allows it to run at a user-determined speed without requiring training shows an opportunity for using Smart Motors with even younger participants who may not have motor and cognitive skills to train the motors.

VI. Conclusion

Smart Motors is an easy-to-use, low-cost alternative for teaching robotics. We designed play-based lessons to help students learn and use Smart Motors in a workshop setting. The analysis of data from the case studies from workshops with elementary and high school level students showed the presence of playful characteristics. Our in-depth analysis of two out of the five characteristics of play (i.e., Joyful and Iterative) showed that participants moved through different states of play throughout the experience with both consistent patterns (Joyful) and individually unique patterns (Iterative). Furthermore, we showed that participants of various age groups can learn to use Smart Motors and engage with them.

The ability to train the behaviors of the motor for different sensors rather than coding those behaviors affords a wide range of unique student outcomes. We will continue improving the Smart Motor design and UI to enable students and teachers to engage in playful learning-based activities, such as adding more sensors and the ability to control multiple motors with a single sensor. The subjects in the case studies presented in this paper may not be representative of the target population. Therefore, in the future, more tests need to be carried out with students with diverse prior experience to examine the impact of Smart Motors in play-based activities. In addition, students' testimonials of their experience should be collected to cross-examine the results. Learning Through Play Experience Tool helped evaluate the teaching practice and Smart Motors. However, in the future, the quantitative approach along with the qualitative approach presented in this paper must be used to analyze the teaching practice as well as students experience.

VII. Acknowledgements

We want to thank Erin Glocke, Kevin Lavigne, Aengus Kennedy and Noah Saxenian for their contributions in the workshops. This material is based upon work supported by the National Science Foundation under Grant No. IIS-2119174.

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