USING DESIGN THINKING AND ROBOTS TO ASSESS AND MEASURE A DISTANCE LEARNING AFTER-SCHOOL PROGRAM

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ABSTRACT

This article describes practitioners' retrospective analysis of an after-school robot learning program they facilitated by analyzing their qualitative notes to assess, measure and evaluate the formative feedback they conducted. The authors use a theoretical framework of Design Thinking (DT) and Constructivism as the foundation of their analysis of the program implementation. The detailed analytical notes used, which supported their reflection on the program's curriculum content as well as the teaching and learning that occurred in the classes, are categorized within the seven DT mindsets. The authors share thematic vignettes from their journey and discuss instructional strengths ("Mindfulness of the Process", "Show, Don't Tell" and "Integrative Thinking") and areas for growth ("Optimism," "Experimentalism," "Collaboration" and "Empathy"). Authors are currently teaching online in different modalities and they are applying the experience learned during this program to their Distance Learning experiences. The authors share implications for practice and for research, among which they also share an annex of a set of four documents, which include a practitioner guide for assessment advice, a reflective note-taking template, an example lesson plan and a lesson plan template. These shared documents have been developed as an evolution from this research and that can be applied to other Informal Settings, including Distance Education environments.

Keywords: Constructivism, Informal Settings, Formative Assessment, Reflective Practitioners, Design Thinking, Robot-Learning, Computational Thinking, Distance Education

INTRODUCTION

This article analyzes a course carried out in an informal setting with a focus on Robot Learning. This program was part of an after-school program during the winter of 2016 in Shanghai, China, and it was co-taught by the primary (PA) and secondary author (SA). This pilot program gave the authors several instructors many insights that they would like to share, and that they are currently using when developing new curriculum, including online courses and other settings beyond traditional classroom settings.

Coming with vastly different academic, work, and cultural experience, with the SA specializing in electrical engineering and robot design from Argentina, and the PA coming from a background in garden-based education from California, an unlikely partnership began. The SA had developed an educational robot, called Plobot (www.plobot.com), with the intention of offering a non-screen tool for children to learn about coding and programming. Upon meeting the PA, it was deemed that her background in experiential education in the informal setting of learning gardens could lend itself to creating a curriculum for hands-on, screenless coding and programming learning using Plobot.

The Plobot pilot curriculum, consisting initially of a set of ten lessons, was implemented in the after-school programs of four international schools in Shanghai. Competing with a plethora of other after-school offerings at each school, ranging from Lego design to clay crafting, the Plobot course hosted an average of nine participants per school and totaled 35 students altogether. Participants ranged from ages six to ten, and sessions were held once per week, directly after-school, for approximately an hour in duration each time.

Plobot's physical design was crafted by the SA and his team in response to the contrasting, culturally trending dual demands for reducing child screen time whilst encouraging computational literacy skills starting at younger and younger ages (Gutnick et al., 2011). The design team conducted many user trials and feedback sessions with children and parents to fine-tune Plobot's physical features and code-ability to ensure a friendly interface for its audience.

A collaborative process ensued between the PA and SA to guarantee mutual understanding between the disparate contexts of electrical engineering, from which Plobot was birthed, and the pedagogy of experiential garden education, in whose framework the Plobot lessons were to be rooted in (Swain, 2009; Carpenter et al., 2004). Over the course of many meetings that included discussions over which codable Plobot behaviors were most valuable and relatable for the student participants to engage with, to thinking through best practices for pre-teaching and modeling Plobot functions to enhance student interest, the Plobot curriculum was hatched. Each lesson began with an interactive PowerPoint outlining robot coding concepts and vocabulary, studded with explanatory videos. These introductions were followed by hands-on experimentation to put the teaching points into practice through exploring open-ended problem-solving tasks using the Plobot. Each lesson introduced a new coding principle with an affiliated program card, posed a problem to be investigated using the amalgamation of coding principles from prior lessons with the day's target coding principle layered on top, highlighted different settings and themes that attended to the students' interests (e.g. Plobot feeds animals at the zoo; Plobot bakes birthday cakes for a surprise party), and incorporated opportunities for teamwork in which partners created coding sequences to enable Plobot to attempt to complete the tasks. To conclude each session, participants could opt to share their varied solutions with the group, receive feedback, and process the experience through answering reflection questions. The blended lesson structure embodied many features that are now, upon retrospective reflection, interpretable as Design Thinking elements.

The theoretical framework of Design Thinking and Constructivism the authors lay as the foundation is a lens on top of the work they did back during the pilot program implementation in 2016. Through the years, the PA and the SA, have kept in touch over the years and are now returning to reflect on the Robot-learning work they did together four years ago with new perspectives, having since gained a Master of Arts in Education (MA) and Multiple Subject Teaching Credential in the PA case, and a Master of Fine Arts (MFA) for the SA, to help us reinterpret and make sense of the work done in the past. Naming this retrospective element so explicitly is important for the authors because their reflections will be most useful if their context is fully transparent, and at the heart of our research rests an underlying question: what, if at all, is the value of processing and analyzing data so far removed from its point of origin? The research focuses on the question of how practitioners can use DT to **evaluate their formative assessment on an after-school robot-learning setting** (and extending its findings to other learning programs).

OPERATIONAL DEFINITIONS

For the purpose of this study, the following terms are defined as follows:

- **Constructivism** is defined as instruction calibrated to the conceptual understanding of the student. The basic idea of constructivism is that the learner must construct knowledge, the teacher cannot supply it (Bringuier, 1980). Constructivism stresses the interaction between learner and the environment and learning is embedded in the context in which it occurs. Thereby learners are encouraged to develop their own understanding of knowledge (Piaget, 1974).

- **Informal Learning Settings** are typically places where learning takes place in museums, zoos, aquaria, science and technology centers, homes, after-school, and clubs. We have operationalized our definition to include distance learning (Hargis, 2001). They are characterized as places where motivation is internal, the content is variable and possibly unsequenced, attendance is voluntary, displays and objects are provided, learners are of all ages, and there is more diversity in the learners' backgrounds (Koran & Koran, 1988).

- **Assessment** is the process of gathering information from multiple and diverse sources to understand learner knowledge, skills & dispositions (Huba & Freed, 2000).
    - Formative assessments gather data on students' processing during instruction. Summative evaluates the students' performance after instruction. The key difference is how assessments are used, i.e., to inform, adjust instruction; or assign grades (Brookhart, 2013).

- **Reflective Practice** is learning through and from experience towards gaining new insights of self and practice. It aims to make one more aware of one's own professional knowledge and action by challenging assumptions of everyday practice and critically evaluating practitioners' own responses to practice situations (Finlay, 2008).

- **Design Thinking** (DT) is an approach to learning, collaboration, and problem-solving. There are several DT models for teaching and learning. This study will primarily use the Hasso Plattner Institute of Design (Stanford School) (Hasso et al., 2011). This study involves five primary steps, Emphasize, Define, Ideate, Prototype, and Test. There are several other derivatives of this model, which include IDEO, International Design, Google Design Sprints, Austin Center for Design, Mary Cantwell DEEP Design Thinking, Design Council UK, Charity for Strategic Design and SAP, Software Programming Company.

- **Robot-Learning** (Computational, Algorithmic Thinking) is a research field at the intersection of machine learning and robotics. It studies techniques allowing a robot to acquire novel skills or adapt to its environment through learning algorithms (Peters et al., 2009).

- **Problem-solving** (PS) typically involves five primary aspects (Shirley & Ng, 2017). First, problems make optimal use of social purposes to impress upon students their collective responsibilities. Second, PS involves identifying issues that are near at hand and then using these as the foundation for further inquiry. Third, firm academic content knowledge is a precondition to successful PS, not a distraction from it. Fourth, developing PS skills requires a teaching and learning process in which speed in the acquisition of new knowledge is combined with respect for "slow thinking" (Kahneman, 2011). Fifth, new digital technologies have become an essential way to disseminate the knowledge gained from PS projects.

LITERATURE REVIEW

Constructivism

The spirit of a constructivist approach has embodied learning for decades and can be seen in many types of environments. From the Socratic method to project/problem-based learning, experiential, cooperative/collaborative, apprenticeship and more (Brown, 2014). The common theme in these approaches is the focus on how the learner brings their personal, prior experiences to the context and identifies the connections between prior, current and potential future ideas (Alt, 2015). It is the connections that hold the power for sustained, deep learning (Alt, 2014). Some constructivists quote this there with a focus on "building blocks." However, we all realize that a solid house maintains its structure by the concrete mortar connecting the brick blocks together. Similarly, concepts are not facts in isolation, but should be mapped to another concept in non-linear ways, so that the learner can create "sticky" multiple paths to access in their long-term memory (Reid-Martinez & Grooms, 2015).

In our study, the focus of engaging students in building robots and coding sequences takes on this metaphor of constructivism, as well as physical building. It is through the intensive hands-on/minds-on activities that learners are able to create opportunities for multiple failed events, each event subsequently leading to a variety of possible future events. Through these calculated trials and errors, the learner processes meaning into their schema (different from memorization because they have experienced the events and realized there is a rationale for why certain aspects of the robots connect successfully to each other) (Pelech & Pieper, 2010). To inspire learner risk taking, this study provided open, supportive space which reinforces intrinsic motivation, methods are unsequenced, and manipulatives were provided, much of which are included in informal learning settings. These findings extend to other programs that are not included in conventional education, carried out outside of formal classroom spaces that might be online distance learning, after-school activities and other programs.

Informal Learning Settings

Koran and Koran (1988) noted that informal learning settings are where learning takes place in museums, zoos, aquaria, science and technology centers, homes, after-school and clubs. Spaces such as these include a substantial amount of hands-on, experiential, collaborative interdisciplinary opportunities for learners to play, communicate and socialize while creating. Hargis (2001) added another dimension to informal settings as he overlaid the attributes of this concept into a learning environment on the world wide web. The author found that many of the attributes translated successfully into the internet. He also identified age and self-regulated learning as key criteria, at the time, for successful learning online.

For our study, the brief episodes and negatively for lengthy episodes; and this effect is strongest if the two affective states are considered together, and weakest if confusion is considered alone. Key to capitalizing on these attributes is timely, helpful feedback often provided as formative assessment, measurement and evaluation.

Assessment

Feedback is critical in a continuous improvement loop and collecting timely, constructive data is essential (Florez & Sammons, 2013). The steps to gather the data are just as critical, as research suggests a multi-faceted informed process which includes formative assessment, measurement and evaluation (Woods, 2015; McMillan et al., 2013). The first step for meaningful feedback is assessment, the process of gathering information; secondly is measurement or an assignment of criteria; and then finally evaluation, which is a judgment based on the first two steps. Assessment for student learning in this project occurred as learners were building their robots, receiving concrete feedback when the system did/did not function. Key to gathering useful assessment data is to create a system and/or instruments for collecting both direct and indirect measures prior to or early in the design phase (Cross & Angelo, 1988). Direct measures attempt to measure exactly what you are intending to measure and can include student artifacts, work, papers, projects, performances, portfolios and direct observations from the instructors using a valid/reliable analytical rubric (Luce & Kirnan, 2016). Whereas, indirect measures attempt to measure the perceived extent of learning, are less powerful and can include surveys (which are difficult to create in the absence of bias) or focus groups with consistent prompts and methods to deviate in a systematic way (Clauss & Geedey, 2010).

For this study, the assessment focus was on the instructors who (1) gathered formative (real-time) assessment data while they were teaching, which they used to modify and update the instruction based on the data (Ozan & Kıncal, 2018); and (2) after the end of the project, reflected on the experience and identified patterns of behaviors in students. This approach of reviewing data in retrospect can be a powerful tool for redesigning the next instructional opportunity. This approach includes more than simply reviewing notes and/or discussing casually with a colleague or co-instructor. The process is systematic, often following a protocol, which ensures clear, consistent, and critical review, which produces actionable outcomes. Instructors who engage in this process are often considered to be reflective practitioners.

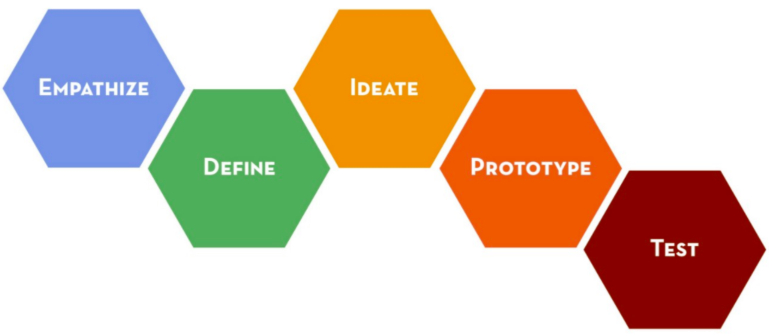
Reflective Practitioners

Reflective practice is often cited as the process of learning through and from experience towards gaining new insights of self and/or practice (Jarvis, 1992; Mezirow, 1981). This tends to involve being self-aware and critically evaluating own responses to practice situations. In this study, the two instructors consistently recorded documentation, discussed each session's outcomes, and modified subsequent sessions as needed. This approach aligns well with reflective practices and empowers the instructors to capitalize on the benefits of increasing self-awareness, which is a key component of emotional intelligence, and in developing a better understanding of our students (Mayes, 2001). Reflective practice has also been shown to help develop creative thinking skills, and encourage active engagement in the work processes (Moon, 1999).

A common reflective practice cycle includes describing the experience; reflecting (in a consistent manner); theorizing; and experimentation (Black, 2001). Luigina (2015) found that reflection works best when the instructor reflects not only on the practical acts of research but also on the mental experience which constructs the meaning of practice. Furthermore, Luigina found that reflective practices are helpful with qualitative research, where it is used to legitimate and validate research procedures. John Dewey (1933) tells us that we do not learn as much from experience as we learn from reflecting on that experience when analyzing the way we think. Farrel (2004), based on this idea, suggests ideas for reflection which include reflecting during and after lessons; performing data analysis; creating teaching journals; requesting peer observations; creating opportunities and guidelines for group reflection; joining Learning Communities; and action research projects.

Design Thinking (DT)

The Stanford Design Lab breaks down DT into five steps: empathize, define, ideate, prototype, and test (Brown & Wyatt, 2010). Brown (2008) suggests a design thinker profile includes key attributes such as empathy, integrative thinking, optimism, experimentalism and collaboration. Brown further emphasizes that the design process is best described as a system of spaces rather than a predefined series of orderly steps. Ultimately, the author suggests three primary steps of the DT cycle, namely Inspiration, Ideation and Implementation. In this qualitative study, we use DT to "Stretch" the design, which allows us to reach deep beneath the surface with participants, encourages each of us to become an observer, and challenges the thinking of client-observers (Sharlip, 2019). There are a number of benefits stretching can bring to qualitative research such as supporting creative potential; bringing disparate voices together; remaining curious and empathic; opening doors to creatively imagining ideas, and embracing failed events. The authors utilized DT to:



- Create empathy between participants and the plobot tasks each session (e.g. tasks were crafted in response to participants' named interests, plobot itself was physically designed with empathy in mind -- goal was to make it more human looking); and
- Prototyping and testing to respond to problem-solving tasks.

There are several challenges with integrating a design thinking model broadly. In Ersoy's (2018) study entitled "Why Design Thinking is Failing and What We Should be Doing Differently", the author sums DT as collaboration, insight, problem solving, building and testing. Briefly, the researcher explains that DT is failing because our brains are limited to the knowledge that we know at that point. Secondly, the author identifies that ineffective collaboration is common, which produces low quality products, although the team had formally completed the DT process. Also, challenges still exist with this relatively new approach, such as inadequate resources, time constraints, fear of poor grades and the difficulty of shifting to a new way of teaching and learning that differs vastly from the traditional approach (Renta, 2016).

METHODS

This study was conducted as an extracurricular, after-school activity offered during the spring and summer of 2016 to four international schools in Shanghai, China. It was a qualitative, exploratory social science design interpreting both direct and indirect measures. The total number of students were 21 male and 14 female students, with ages 6 to 9 years old. Each school had a unique composition of students in a group from 6 to 11, with mixed nationalities and cultural identities.

Each group met weekly on a fixed day with one instructor and one teaching assistant. The students participating in the activity were signed up by their parents by the beginning of the academic year. The duration of the program would last between 10 and 12 weeks, with each session running from 50 to 75 minutes. These ten sessions took place during two semesters, with four instructors and teaching assistants (TA) over the course of the time.

The space used for the activity was either a regular classroom space or an art studio. The instructor and assistant would arrive early to set up the space for the activity. In most cases, this would entail creating a floor space for the kids to sit down and ensure that a whiteboard and audiovisuals were ready before students arrived.

DATA COLLECTED

Before each session, the instructor prepared a document of two pages' length describing the activities, learning outcomes and class objectives. A set of slides with audio visuals would be produced as a supporting teaching material. After each session, the instructor and the assistant would take notes registering the date, the teaching material used, the location and the attendance of the students. Within these notes they would also record the activities, anecdotes from the workshops, data from the students, outcomes and remarks about what aspects went well or could be improved. After filtering the raw notes and pre-classifying notes into individual entries, the resulting database compiled had over 200 comments with an average of 96 characters per comment.

ANALYSIS TOOLS

Following guidelines for inductive research (Strauss & Corbin, 1990), and using as an inspiration the analysis of a science, technology, engineering and mathematics (STEM) after-school program (Carrol, 2014), the notes were read and re-read several times. The annotations of each day were subdivided into several sub-items, creating a granular matrix that could help us to evaluate the data in clusters. This approach to group the notes in subthemes helped the authors to describe the interactions between the learners and the materials while allowing a qualitative reflection instead of a quantitative assessment of the program.

Unlike traditional learning methodologies, DT follows a two-fold part being both a mindset (Carrol, 2014) and a dynamic non-linear process (Serrat, 2010). What sets DT apart from other approaches is that it focuses on the process instead of the product. And as a creative process, it follows a mindset that is human-centered, action-oriented, prototype-driven, and non-judgmental (Carrol, 2014). Thus, it espouses positivity and eliminates the fear of failure, and maximizes input and participation from the participants (Lor, 2017).

Analyzing class notes with a lens of the mindsets proposed by Brown (2008) and considered DT as a dynamic and non-linear framework (Scheer et al., 2011), the Stanford DT model was used. The following are the seven mindsets used on the reflection side of the research:

1. **Show, don't tell:** Communicates ideas in an impactful way. Expresses ideas in non-verbal ways. It finds opportunities by other means than discussion. There is an inspiring vision that

fuels ideation. Putting making over thinking and discussing.
2. **Empathy:** It puts "people first" noticing details that others ignore. Clearly addresses issues that others have. The focus of the solutions is human-centered.
3. **Integrative Thinking:** It doesn't rely on analytical processes. It gets to explore deeply issues, even contradictory ones.
4. **Optimism**: Assumes at least one potential solution to challenging problems.
5. **Mindfulness of the Process:** It's thoughtful about how solutions are implemented. It analyzes how to improve the methods used.
6. **Experimentalism**: Poses questions and explores constraints in new directions. Prototypes and builds as an integral part of the process. It receives feedback for better solutions.
7. **Collaboration:** Seeks interdisciplinary and multidisciplinary collaborations. It explores solutions from diversity. It engages in diverse innovations from people of different backgrounds.

REFLECTIONS

Interested in if and how our Plobot program instruction allowed for a DT experience for participants, class reflection notes were reviewed and classified using DT mindsets as categories. As is the reality with most categories, although they are listed as discrete and separate, the authors acknowledge that the mindsets are innately overlapping and intersectional in nature. As such, in several cases, individual comments were considered in more than one DT mindset. Using the instructor notes as the evidence in the above-mentioned categories, the following selected quotes comprise the following thematic vignettes (Carroll, 2014).

Show, Don't Tell (n=46)

"Kids were very excited to take something home, I saw students showing the finished product to parents and everyone seemed pleased." "Grace made a beautiful song". "Students used lesson 7 for this session: where student uses musical notes to buy supplies for a surprise party"

The quoted comments listed above indicate the instructors' noticing of instances of students "showing". A key characteristic of our program was the open-ended opportunity in each session for students to create, to take ownership over the concepts by fashioning code sequences and manipulating robot materials to produce their own code and even their own robots. The dense opportunities for making led to both students and instructors physically demonstrating conceptual understanding. Themes such as preparing a birthday party, visits to a wild animal zoo, or performing on a talent show helped to establish a group dynamic of valuing the visuals, crafts, performative movements, and sounds as a manifestation of the internal processes.

Empathy (n=25)

"Excited about hosting the 'surprise party': the theme seemed to resonate with the kids because we chose 'guests' that everyone was excited about". "One student (J.) was distracted but eventually helped his partner make a circle".

As the instructors, we hoped to instill a culture of mutual respect and care in the after-school program learning community. We as instructors hoped to demonstrate our care by framing Plobot activities to respond to the named interests of the students (e.g. selecting prompts for tasks that included people or topics that the children stated excitement about). We hoped that by building our own empathy for the students into the design of the courses, this would translate to the participants forming stronger relationships to the tasks and to each other. The instructor reflection comments here imply that our strategy, to some degree, was effective.

Integrative Thinking (n=46)

"We had very insightful/creative ideas when we were brainstorming what the essentials were for making a robot (one student described it as creating an 'ecosystem' with the different hardware and software

components)". "Today was a full hands-on class day: did challenges with 'avoid obstacles', line tracking, bouncing in borders, and saw how 'follow torch' worked with a demo: students extremely engaged with the new robot model, liked creating routes for him, interacting with the 'scan barcode' program method and made insightful observations comparing different kinds of robots and how to program them."

We had a holistic approach to the class preparation, shared content and planned the conversations. We purposely sought to provide opportunities for students to bring their own vocabulary and experiences to the activities proposed by the instructor. Sometimes this resulted in a group of students utilizing prior knowledge from other sessions in a new way, or sometimes bringing in different angles or sensitivities that allowed for a new perspective.

Optimism (n=29)

"Some groups finished all the challenges and had some extra time so invented their own extra challenges and stayed engaged with plobot and the theme". "Students strategize best routes for sending plobots, I had to use estimation and got a lot of work in with the direction programming cards'. "Students learned how to use 'repeat': all students were able to accomplish the tasks using the repeat card successfully."

Despite the difficulties and challenges faced, instructors always encourage students to embrace the positive aspects of the outcomes. Sometimes, this took the form of acknowledging the diverse skills that contributed to the success, thereby diverting away from clearcut success vs. failure feedback models that students might be used to in regular school day activities.

Process (n=50)

"Students carried out the concept of shopping with the notes: incorporating math into their problem solving would be the right approach". "Some groups finished all the challenges and had some extra time so invented their own extra challenges and stayed engaged with plobot and the theme". "had to explain a lot in the middle of the lesson which was slower/maybe more confusing". "We only managed to get through the first game (what time is it mr. fox?) because we played multiple rounds, but students were very engaged so we stayed with it"

We tried to create the conditions for a nurturing playground environment to foster appreciation for each of the steps on the pathway to learning something new. This translated to the way we delivered the classes, as a flexible, responsive learning community that adapted to the needs of each child in the space, speeding up or slowing down activities to allow students to get acquainted with topics that were not familiar to them at their just-right pace. The comments above show indicators of these teacher-student moves; the adjustment and differentiation implemented to scaffold the tasks for different individuals and groups.

Experimentalism (n=28)

"Good idea of changing the plobot colors for different levels. kids felt motivated by the idea of 'competition'/'challenge'." "Promote the idea that they can create their own well thought out songs more (not just random notes, but actually thinking about how it sounds), because these students are more musically inclined".

Having open-ended activities that allowed students to create their own outcomes, and piecing together what they wanted to present and share with others was present in many of the lessons. This spirit of disrupting the dynamics of the "instructor" knowing the correct answers and the "students" having their performance assessed required a conscious effort that underpinned both the design of new activities and the way that the students perceived the classes themselves.

Collaboration (n=25)

"I saw some teamwork: kids helping each other if others were behind on a step." "Encouraged each

other with applause". "Worked really well in teams." "Students enjoyed interacting with plobots, each other across the classroom: also challenged them because they had to be patient to send/receive plobots from other classmates' '.

The concept of teamwork and collaboration as an essential part of success was part of our conversations in and outside of the classroom. Moving from individual participants as disparate units to formulating a small learning community that helps and relies on each other originated with the instructor sharing their experiences and traveled through the lessons and interactions to pairing and grouping students who have complementary skill sets that would productively challenge and enhance their social-emotional and robot-learning experience.

DISCUSSION

Were we able to provide a platform through which we perceived students as expressing these seven DT mindsets? The following processes the trends identifiable in the Plobot program comments, and asserts possible next steps for future lessons based on this information.

In reviewing our comments, and attempting to return to the moment in time in which they were written to attempt to classify them into the seven mindsets, we were able to identify some of the mindsets as strengths and some as areas for growth. The lens through which we conducted this analysis requires further rigor, and we seek to return to the data with other modes of understanding in the future, however, what we offer below is a starting point.

Strengths

When we analyzed the thematic vignettes grouped in the seven DT mindsets, we perceived that our formative assessment comments demonstrate that "Mindfulness of the Process", "Show, Don't Tell" and "Integrative Thinking" were areas that were thoughtfully explored during the program. Firstly, the instructor notes assessment imply that students were invested into improving their problem-solving methodologies ("Mindfulness of Process Mindset"). In addition, students were seen to exhibit creative expression through making and demonstrating rather than only verbally explaining how they approached the open-ended Plobot tasks ("Show, Don't Tell Mindset"). Finally, instructors interpreted participants as engaging with the Plobot tasks in an exploratory fashion, using creative means rather than rote procedures to work through posed challenges ("Integrative Thinking Mindset"). In sum, this trifecta of mindsets suggests that Plobot instruction was most effective in promoting student engagement in physical manifestations of alternative approaches that valued process over product.

Areas for Growth

"Optimism," "Experimentalism," "Collaboration" and "Empathy" all demonstrated lower frequency in our instructor note assessment. The lower occurrence of comments regarding the presence of these mindsets in our lessons hints that we did not as inherently facilitate students' assumption of a possible solution (Optimism), resilience in trial and error operations in problem-solving (Experimentalism), undertaking of interdisciplinary partner work (Collaboration), and overall human-centered approach (Empathy). We believe that progress is required to enhance participants' DT experience of Plobot in these symbiotic regards (Dam & Siang, 2019).

Optimism, Collaboration and Empathy, all falling within a "social intelligence" category, assisted by strategies to foster Experimentalism, could be improved in the Plobot curriculum in a number of ways (Goleman, 1998). For instance, according to Social Cognitive Theory, explicit teaching followed by team building games with familiar tools and topics could model and allow time for students to see and practice partner and group work before being invited to do this with Plobot (Bandura, 1965). Other interdisciplinary strategies include inserting more introductory prompts in the form of visualizations or improv that encourage the students to think more deeply about the characters in the lesson's story, yielding participants who are more socio-emotionally attuned to the Plobot's challenge that day (Bandura, 1989; An Educator's Guide to Design Thinking, p. 3). Adding more emphasis, through contributing additional time and tools to the prototyping phase, is a way to boost engagement with the

Experimentalism mindset, as when participants have more time and resources for planning and mapping to explore an open-ended question, they are more likely to invest in the trial and error required for a rich experience (An Educator's Guide to Design Thinking, p. 4). Ultimately, upon developing future lessons, building on the strengths and areas for growth noticed in the dataset's trends, it would be advisable for the robot-learning instructors to adapt their plans and implementation accordingly.

Analysis Revisited

Our original assumption was that each of the seven mindsets of DT (Carroll et al., 2010; Lande, 2010) should be weighted evenly. However, we highlighted this early sorting methodology as harmfully oversimplified and unsubstantiated. Therefore, we went back to the research behind the seven mindsets to think more thoughtfully through the data's trends and what they might mean.

As stated in the Discussion above, we recognize that the data can be classified through other mechanisms to assist in reaching greater understanding about the work we did with Plobot. A key issue we came up against was how to designate the weight of each DT mindset. Once there is a more standardized understanding of best practices for how much time and attention should be assigned to each DT mindset or phase, we can potentially evaluate our data in more straightforward terms. However, as non-linearity, iterations, and weaving in and out of different phases with a human-centered focus are part and parcel of DT itself, it is potentially unlikely that standardization will occur because it is explicitly against the principles of DT (Dam & Siang, 2019). The readers might kindly excuse our messy reflections as inherent to the DT way.

Yet, at the same time, there is potential for creating a more streamlined system for benchmarking weights of the different DT mindsets or phases that could act as a tool for interpreting data to an extent with limitations. For instance, as seen in workshop timetables (Innominds Innovation Training & Consulting, 2020; Stevens, 2019), we could use the approach of cross-referencing the seven mindsets with the average amount of time spent at Design Thinking Conferences or classroom workshops for each stage of DT to help us better compare our reflections to what is institutionally expected of DT processes, or to assist us in arriving at how much weight should be attributed to each mindset. Or, by evaluating research by the firm Nielsen Norman (Gibbons, 2016), we could assess the time and emphasis DT practitioners attach to the different mindsets and phases.

LIMITATIONS OF RESEARCH

Further data is required to offer a deeper and more refined understanding of how practitioners can use DT models to effectively interpret formative assessment data. The sample size and timeline, limited to four instructors' comments whilst working with elementary school students at four affluent international schools' after-school programs over the course of six months, is not able to capture a substantial longitudinal and diversified interpretation of the impact of our methodologies (Nind & Lewthwaite, 2018). In addition, while we had the foresight as early robot-learning practitioners to record our reflections on our weekly after-school sessions, and use these notes to inform our next instructional moves, many gaps are evident in our data. For instance, although we have ample written comments from instructors, we do not have data from participants. We only have the perceived impressions of the instructors on whether or not students demonstrated evidence of the (again, limited in scope) seven DT mindsets we identified; we are not able to time travel back and be more rigorous in naming predetermined signs and keywords that could be stronger indicators of whether or not students actually exhibited evidence of these mindsets at the time of the lesson enactment.

The comments, as the primary dataset for the study, often exhibit use of descriptive terms that assign value judgments to what the instructors experienced the kids doing, e.g. "kids were excited", "kids enjoyed" or "kids were enthusiastic about...". These comments tell, but do not show, thereby eliminating the neutrality of the observation. Now, as more experienced educators with more training and understanding - it is clear that these comments would hold far more meaning if they were to embody more "show" (Husbands & Pierce, 2012).

Moreover, the four-year gap between program implementation and our current interpretation of data allows space for false memories and other undesirable errors. Bias is inherent in our study, as we are interpreting what we thought we meant by comments made four years ago about kids' behaviors. Then again, being fully "scientific" and unbiased about collecting and interpreting student data at any moment, directly after the encounter or years later, is riddled with bias and variables regardless (Hattie & Timperley, 2007). There are no known controls for children and their individuality; we cannot predetermine how different students might interact with a tool to engage with a prompt. include that it's hard to replicate and get consistent percentages when looking at reflection comments.

MORE TO EXPLORE

Implications for Practice

If we were to implement sessions again, given the academic and lived experience we have gained since the first Plobot pilot sessions in 2016, we would be more specific and rigorous in our formative assessment and data collection approach. The following descriptions speak to planning and reflection tools we developed for grounding design thinking workshops in meaningful, responsive engagement and formative assessment. Several of these documents continued to evolve according to the authors' practice, including other informal settings and online education. These items can be found linked in the descriptions below.

The intention behind offering these tools is to save educators the hours of time laboring over creating lesson plan formats that attend to DT principles, and spending the hours processing assessment data. Pulling from lessons learned from our pedagogical, design and teaching experience, we formulated templates and advice to facilitate educators' access to thoughtful and quick translation from note-taking to feedback and action. Educators are encouraged to modify and redevelop these tools in whatever way suits their particular setting and teaching style, what we present is merely a launching point/touchstone from which educators can craft what is best for them and the learners they work with.

1- Show, Not Tell -- Assessment Advice

This document compiles the latest research on effective formative assessment and translates it into a simple document for educators to use and reference. Although we did not know about this research at the time of the 2016 Plobot Program, we do know about it now, and we see that having this information could have helped us write more concrete and actionable reflective comments on our class sessions rather than the loose notes we sometimes took, as we described in the Limitations of Research section. We now know that effective formative assessment and consequent feedback should be specific, timely, goal-oriented, clear, thoughtful, and embed learner involvement (Stenger, 2014). The assessment advice document, intended to be reviewed by educators to inform the way they take anecdotal notes and relay feedback to learners based on those notes, is offered in a user-friendly page to be digested and utilized for immediate use.

2- Reflective Note-Taking Template -- Conducting Formative Assessment with the DT Seven Mindset Framework

The Reflection Template available in the appendix offers a space for educators to capture their anecdotal notes directly into the Seven DT Mindset categories utilized in our study. We recommend that the Reflection Template be used in conjunction with the Assessment Advice sheet, as the sentence starters and frames from the Advice Sheet can be responsively inserted and completed inside of the corresponding DT mindset sections on-the-go during lessons. By using these organizational formative assessment structures from the outset, educators can avoid long processing intervals that tend to swallow the time between when instructors take notes and properly review them to make sense of them, and between when a student performs a task and when they receive meaningful feedback.

3- Sample Plobot Lesson Plan

An example of one of the original lessons we worked from serves as a model of the Plobot Curriculum described in this article. We include it in the hopes that it adds clarity and visual aids for readers seeking to understand our approach.

4- Lesson Plan Template

Though our article centers on formative assessment, it is clear that effective assessment is inextricably linked to the instruction to which students respond. As such, we also include a lesson-planning template that can be used by educators facilitating workshops in an informal setting or in the classroom which incorporates opportunities for the installation of DT elements. While the lesson structure is only limitedly tweaked from its original format used in the first set of 10 Plobot lessons, the lesson plan's alterations attend to the strengths and areas for growth evident in the trends from this study. For example, increasing time allotment for experimentation is a critical new addition.

As intentional as we may be in our planning for instruction and assessment, the facilitation itself, the way the knowledge and materials come together with instructors and participants in the sessions, is a critical piece that requires the instructor's just-in-time teaching moves to use what they know to respond to the needs of the learning environment.

Implications for Research

More longitudinal, diversified studies are required to fill out this category of research at the busy, rich 21st century intersection of reflective practitioners, Constructivism, computational literacy, and a DT approach. Of particular interest to use is the consideration of instructors as reflective and design thinkers themselves. In retrospect, we realized that, as we created and implemented DT experiences for students, we simultaneously employed design thinking processes for building our own instruction.

Looking back on the Plobot program of 2016, there is evidence for embedded elements of design thinking for both participants and practitioners. We will delve deeper into this duality of the DT experience in future articles. We also continue to wonder and seek to explore:

- Which of the seven mindsets hold more relative weight than the others? How and why?
- How can STEM practitioners effectively utilize just-in-time formative assessment and feedback within a design thinking framework?
- How can we incorporate the variable of a trusting teacher/learner relationship as a component for assessing the effectiveness of after-school programs?
- How do uniquely implemented responsive, just-in-time instructional moves impact different learning communities using the same written curriculum?
- What is more, the lingering question remains that this article only just starts to scratch the surface: is it worthwhile to retrospectively search for meaning in teaching and learning experiences from our pasts? If so, to what end?

FURTHER DISCUSSION

It has felt purposeful to conduct this reflective study on the 2016 Plobot program, to try to reinterpret the instruction we conducted then through new frameworks. Returning to the past to apply imaginative methodologies for data interpretation proved itself to be an immersive opportunity for professional development. Refining roadmaps for formative assessment, especially through the analysis of a shared program with partner practitioners four years later, allowed for a weathered honesty and clarity one sometimes only achieves when looking back through the rearview mirror.

The lessons learned continue to inform our practice as educators today, while both of the authors now teach in different online modalities. Though it has its drawbacks, the DT framework helped us see and sort our data in original ways that highlighted new insights and gaps in the user experience of the Plobot curriculum. Returning to prior work with seasoned but fresh eyes also enabled us to develop resources to support ourselves and possibly other practitioners in avoiding understandable stumbling blocks to gathering and processing meaningful data, because we have been there, and back again. It was powerful to return to the robot-learning work of an early career to find that there are still lessons to be learned from it, for participants and practitioners alike. The authors would also like to share their enthusiasm for extending these findings and reflections associated with their experience to distance education programs like the ones they are currently conducting online.

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