Participatory Design and Learning Outcomes: Designing a Citizen Science Portal with Elementary School Students

by

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Abstract

This paper explores research in Participatory Design when working with student populations. It combines existing design frameworks and integrates them with the Montessori Method and 21st Century Skills to produce learning outcomes that can satisfy curriculum standards in public schools. Using the method proposed in this study, teachers and designers have a way to incorporate the design process in a public school setting. The study followed a group of elementary school students through the design process to create a Citizen Science Portal. The process included research, design, prototyping, testing, and revision.

KEYWORDS: Participatory Design, Montessori Method, 21st Century Skills, Citizen Science, Learning Outcomes

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Introduction

Evaluations of children as design partners in Participatory Design (PD) are found throughout the Interaction Design and HCI literature. Researchers have addressed some of PD's limitations, such as lack of a specific framework and limited opportunities for children to collaborate and experiment with different design roles. For instance, in "How Many Roles Can Children Play?" the authors (Landoni, Rubegni, Nicol, & Read, 2016) noted that children are often not involved in the full spectrum of the design process. Rather, they are limited to small design activities that may not merge with the whole process or product. Likewise, the authors of "Giving Ideas an Equal Chance: Inclusion and Representation in Participatory Design with Children," (Read, Fitton, & Horton, 2014) addressed the tendency of PD to marginalize children's roles, for instance, by only using them for feedback. Instead, the authors suggested a system allowing children to "know how and where their inputs go" (p. 105). These techniques helped children become full participants in the process.

Lack of a framework in PD is also addressed in the literature. Walsh, Foss, Yip, and Druin (2013) created a framework to help designers plan and facilitate design sessions with children. While Sanders, Brandt, and Binder (2010) suggested a three-pronged framework to involve non-designers in the PD process. However, little is written on how to frame PD so that it fits within the traditional educational setting. While research by Barendregt, et al. (2016) supports the need for PD to address learning outcomes when working within a school environment, it also showed that designers are often unaware of how design goals and educational goals differ. This disconnect makes design programs difficult for public schools to adopt.

In order to observe how the design process can be integrated in the classroom, this paper followed a group of 4th and 5th graders through the PD process in a public school setting. This paper proposes an integrated approach to facilitating design sessions with students by combining PD methods, the FACIT PD framework, the Montessori Method, and learning outcomes based on the New Jersey Department of Education's Curriculum Standards and 21st century skills. Through this multi-dimensional approach, I will show that design projects can be tailored to fit within the traditional structure of public schools while offering hands-on, design-centered learning experiences for elementary-aged children.

Chapter 1: A Combination of Disciplines

Literature Review

Participatory Design

PD originated in Scandinavian countries where it "grew out of a democratic movement to give factory workers a voice in the design of technologies intended for their use" (McNally, Guha, Mauriello, & Druin, 2016). Over the years the process has been adapted and refined; one outcome was to give children "a voice in the design of technologies they are meant to use" (McNally, et al. 2016). In the realm of PD children's groups, there are numerous subtypes of the design process, including Informant Design (Scaife, Rogers, Aldrich, & Davies, 1997), Bonded Design (Large, Nesset, Beheshti, & Bowler, 2006), and Cooperative Inquiry (Druin, 1999).

Druin (1999), one of the leaders in forming and shaping new PD methods for children, also coined the phrase "design-centered learning" (p. 592) for the learning outcomes associated with PD. She stated that these learning outcomes can affect all parties involved in the PD process: learning outcomes are not only for the student. Druin (1999) noted that regardless of skill level both child and adult learn when engaged in the PD process. In this way, her proposed framework makes a bridge between a free-form collaborative process and a structured collaborative process with measurable outcomes. Druin's (1999) theoretical framework for cooperative inquiry established "(1) a multidisciplinary partnership with children; (2) field research that emphasizes understanding context, activities, and artifacts; (3) iterative low-tech and high-tech prototyping" (p. 593). Her research suggests a need for designers to re-examine and create new ways for children to participate in the PD process.

Meanwhile other researchers have added structure to PD and offered designers frameworks to follow when facilitating children's groups. For instance, Derboven, Van Mechelen, and Slegers (2015) offered a multimodal approach to PD, wherein researchers compare and contrast different types of outcomes. These outcomes included transcripts of conversations, writing, and tangible products such as prototypes. The authors used four steps to compare and contrast outcomes in order to recognize underlying themes in the design. They then identified values supporting those themes to find patterns and trends in the group's design thinking. Barendregt, Bekker, Börjesson, Eriksson, & Torgersson (2016b) offered another PD framework that supports learning and provides a basis for measurable outcomes. Their process included creating "learning goals, stage activities, and include reflection as an integral part in the PD activity" (p. 167). They asserted that their structure encourages "legitimate participation" where students are part of a dynamic relationship balanced between acquiring skills, learning goals, and design outcome. This relationship directly opposes the traditional design approach wherein product outcome is the only goal.

Another practical framework suggested by Walsh, et al., (2013), offers designers a template for PD creation and planning. The authors created three main categories: partners, design goals, and techniques. Each category has dimensions that PD practitioners use to balance activities and collaboration. For instance, the partner category has two dimensions: partner experience and the need for accommodation. The need for accommodation is on a scale. For an activity that requires taking notes, children who can write form one group, because they do not need accommodations, while the children who cannot write form a group needing accommodations. With these multi-dimensional categories, the FACIT PD Framework is a detailed planning tool that helps set the stage for measuring learning outcomes.

Learning Outcomes in the Design Process

Learning outcomes of the design process have been addressed only marginally in design literature. This lack directly affects opportunities for designers to collaborate with schools where learning outcomes are key to curriculum standards and Board of Education approval.

The paper “Considering Context, Content, Management, and Engagement in Design Activities with Children” (Mazzone, Iivari, Tikkanen, Read, & Beale, 2010), offers designers an outlook on working within the confines of a school environment. The authors outlined a framework that gives a method to gauge children’s participation and contributions in the design process. They suggested that the combination makes for “meaningful design activities” (p. 108). They argued that children’s individual design contributions must be viewed through context and content alongside the implementation of design activities that must feature group management and engaging work. Their final framework categorized design activities by their “aim,” “design contributions (context, content),” and “activities (manage, engage)” (p. 114). The authors advised including teachers in this process because learning outcomes may be more easily created through teacher-designer collaboration.

Barendregt, et al.’s (2016b) research reiterated the need for more teacher and administration friendly frameworks in order for design activities to be adopted within the school environment. The authors approach to PD organized the design process in sections: one for students to formulate, one to perform activities, and one to reflect. Reflection, they argued, is of upmost importance for the individual student to meet learning goals. In their study, master’s program design students were sent into school classrooms to facilitate PD sessions. The reflective portion of the process was not only a moment for students to discuss changes in design, but also an opportunity for individual reflection on the design process itself. This included reflecting on the student’s place in it and skills learned. The authors found that this moment of reflection bridged the gap between judging the success of a design and success of the design process. It was a learning opportunity. In this way, designer and educator were able to see if “design method and the learning goals are aligned with each other” (p. 172) because “PD activities with children should also be explicitly meaningful in themselves for the participating children and adults” (p. 167). This does not mean that teachers must forego learning goals. Rather, using the authors' suggestions to define learning goals might allow a PD approach to be adopted within a school setting.

The idea that PD success centers on a child's involvement is echoed by Barendregt et al.’s (2016a) study “The Role Definition Matrix.” They proposed that designers "consider whether children's involvement is defined from the perspective of the designer or from the perspective of the individual child" (p. 581). This supports the framework also suggested by authors Barendregt et al., (2016b) where PD sessions do not address design only, but also allow for reflection by children as designers and students. Thus, learning outcomes are connected as a student reflects on his/her role as a design participant and a design student. The child sees not just the roles he/she played, but also the outcomes of the design in relation to participation and learning.

This kind of learning, labeled "design-centered learning" by Druin (1999), generally does not have content knowledge outcomes, but rather fulfills other "modern educational goals" (McNally, Mauriello, Guha, & Druin, 2017, p. 5738). These soft skills are being written into public school standards in many school districts, as straightforward facts and rote memorization are being made obsolete by modern networked knowledge and technology. The International Society for Technology Education has stated, "Advances in technology have drastically changed the way we interact with the world and each other. The digital age requires that we understand and are able to harness the power of technology to live and learn" (ISTE - International Society for Technology in Education, 2017). Indeed, the 21st century skills listed on New Jersey's Department of Education website ("New Jersey Student Learning Standards: 21st Century Life and Careers," 2017), encourage critical thinking. Creativity, collaboration, and communication are listed as "The 3 C's" crucial to navigate a digital landscape where content is easily accessible, but the ability to transform and communicate that content is not. The more progressive school districts within New Jersey are incorporating 21st century skills into their curriculum and content standards, as these skills enable students "to make informed decisions that prepare them to engage as active citizens in a dynamic global society and to successfully meet the challenges and opportunities of the 21st century global workplace" ("New Jersey Student Learning Standards: 21st Century Life and Careers," 2017).

Educational Approaches

Papert, the author of *Mindstorms: Children, Computers, and Powerful Ideas* (1993), foresaw the adoption of 21st century standards. Papert noted that "the key learning affordance of computers (which smartphones essentially are) is not to program the child through tasks and answers, but instead to be a tool for exploration and expression through the construction of artifacts" (p. 248).

Papert's (1993) statement, which encourages designers to create technologies that support learning experiences, is decidedly a constructivist viewpoint. Constructivist Theory purports that "people construct their own understanding and knowledge of the world, through experiencing things and reflecting on those experiences" (p. 67). Not only does the student need hands-on participatory learning experiences, he/she also needs a teacher who acts as a guide through those activities. This a radical shift from traditional educational approaches, in which activities are focused on memorization and the teacher, who is the main disseminator of knowledge.

Some alternative educational methods, such as the Montessori Method, embrace the notion that learning is a relationship between student, environment, activity, and teacher. Montessori educational philosophy is one of child-centered learning within carefully constructed classrooms. In the Montessori classroom, the child follows his/her interests and chooses which activities to work on. Each activity is laid out in a way as to be explored and discovered at different levels, similar to the discovery and creation process used in design. It is problem solving at its core. Classrooms and the activities in them are carefully planned to realize the overarching theme of freedom within constraints. Not every activity has a specific educational goal, but a range of functions that ultimately add to the child's educational whole.

When I worked as a Montessori teacher I divided my classroom into sections: math, language, practical life, and sensorial. Individual activities allowed the child to work through lessons progressively, mastering skills until the whole curriculum was completed. Each activity was a micro-lesson that removed grand, multi-step learning outcome expectations. Instead, this one-to-one ratio of learning outcome to activity delivered a whole-system approach to subjects. The emphasis was on the whole. In this way, the design process inherently mirrors the Montessori Method. There is freedom constrained by the problem; the solution only limited by imagination and materials available.

While PD designers have adopted Montessori's idea of the student-teacher relationship and the collaborative aspect of constructivism, there is no literature exploring this dynamic. In order for public school education to adopt open-ended constructivist activities, learning outcomes must be assigned. The question remains: Can PD in school environments assign learning outcomes?

According to researchers, the answer is yes. Kolodner (2002) developed the Learning by Design method to teach students science through subject-related design challenges Reviewing this approach, the author noted that students became competent in 21st century skills, such as "collaboration, communication, design, and science" (p. 19). Assessments were based on both results and skills that were used as indicators of engaged learning. The author contends that learning outcomes based conjointly on these criteria allow teachers to "differentiate good use of skills that led to not-so-great results from mediocre use of skills where luck or previous knowledge or ingenuity allowed good results to be accomplished anyway" (p. 23).

Similarly, a proposed framework by Barendregt et al. (2016b) is constructivist. The authors suggested adapting PD activities to incorporate learning goals. They encouraged designers to involve teachers in their three-step process of defining the learning goal for the design project, communicating learning goals, and allowing time for reflection. They noted that "defining learning goals was no straightforward task" (p. 170), but to "make PD activities explicitly meaningful to children in a school context is crucial for those practitioners and designers adopting the underlying values of participatory design" (p. 172).

Opposing this design trend, traditional educational methods define the teacher's role as directive and based on authority ("Constructivism as a Paradigm for Teaching and Learning," 2017). This notion is counter to the constructivist approach. PD, constructivist in nature, requires teachers to be more like guides where their part is interactive and based on negotiation ("Constructivism as a Paradigm for Teaching and Learning," 2017). Furthermore, in School Friendly Participatory Research Activities with Children (Horton, Read, Mazzone, Sim, & Fitton, 2012), the authors noted that "teachers gain tremendous knowledge, … by having the luxury of being just observers of their class." PD does not consider observing and reflection a luxury, but rather a necessary part of the process for everyone involved.

Today teachers are no longer the sole disseminators of knowledge, as newer technologies and faster information retrieval systems are developed. Instead, learning through a constructivist approach is being embraced by a number of school systems. PD designers, in many instances, are leading the way for schools to include 21st century skills through the design process, while researchers offer practical frameworks for integrating learning goals into design lessons.

Why Citizen Science?

Citizen science is hands-on, collaborative, creative, and communicative. It encourages the building of all 21st century skills, in addition to being a constructivist activity that matches well with PD practice. HCI researchers have delved into the participatory nature of citizen science, including research by Qaurooni, Ghazinejad, Kouper, and Ekbia (2016), that suggested a two-fold definition of citizen science as "one that puts citizens in the service of science and another that involves them in the production of knowledge" (p. 1822). Regardless of whether a citizen science activity is more involved in sourcing data or analyzing it, the experience is still PD that turns "users from informants into participants throughout the design process" (p. 1822). In their research, the authors defined "critical engagement" (p. 1825) as shared between PD and citizen science. For example, they deemed the Neighborhood Network project successful because it balanced activity to participation to reflection. The project was designed to "involve the public in the conception, design, and implementation of a public project that allowed them to take part in the improvement of their environment" (p. 1825). In this project citizens were active participants in all aspects of the design process from data collection to analysis. The authors concluded that the project was successful in both the design of the product and the process. It was a learning experience that "equipped them with technology that would allow them to understand and intervene in the process" (p. 1825).

In "Being Present in Online Communities: Learning in Citizen Science" (Mugar, Østerlund, Jackson, & Crowston, 2015), the authors researched citizen science projects that gave participants "opportunities for access, feedback, and relationship building" (p. 129). They found that to engage novice and advanced users, successful platforms allowed for "multiple and overlapping forms of presence in crowdsourcing environments" (p. 137). Their study showed that successful platforms supported numerous ways of interaction. The authors encourage designers to "strive to support dynamic boundaries that allow newcomers to weave multiple forms of presence together in their ongoing learning effort" (p. 137).

Table 1

Gaps within literature on PD, Learning Outcomes, Educational Philosophy, and Citizen Science in relation to a public school setting

Theme	Not Addressed in the Literature
Participatory Design	Framework to run PD as a legitimate learning experience that meets curriculum standards.
Learning Outcomes in the Design Process	Guidance in assigning state- mandated curriculum standards to design activities.
Educational Philosophy	Template to outline constructivist activities and role of designer in a public school audience.
Citizen Science	Guide to varying roles for teachers, administrators, students, and community in the design and ongoing participation of citizen science projects.

Chapter 2: The Frameworks

Method

For this study I combined a number of templates and techniques to plan and to create design lessons appropriate for a school setting. First, I used the FACIT PD Framework (Walsh, et al., 2013) as a basic outline to gauge the feasibility of the project. Using this template I was able to measure the project's possibilities, limitations, and materials needed as they related to each individual group within the design team: the student participants, the teachers, and the researcher.

Next, I created design sessions based on the PBS DESIGN Squad (DESIGN SQUAD, 2017) process and measured activities against the key tenets of child-centered learning as proposed by the Montessori Method (Lillard, 1972). In this way, I made sure each session's activity was constructivist in approach. Last, all activities were matched to the 21st century skills list as found on the New Jersey Department of Education's website ("New Jersey Student Learning Standards: 21st Century Life and Careers," 2017). In order for the design process to be accepted by public schools' curriculum committees and administrations, design activities must prove their educational merit by supporting learning standards and outcomes.

Applying the FACIT PD Framework

The FACIT PD Framework (Walsh, et al., 2013), offers guidelines for PD design groups comprised of intergenerational team members. In this study, the team members' ages ranged from students 9-10 years old to teachers up to 50. The table below uses the

FACIT PD Framework to map out the dimensions of the project, the level of skill expected, and activity ideas with materials list.

Table 2

Application of FACIT PD framework

Dimension	Level	Notes	Activity Options
Partner Experience	Medium/high	This group has worked in a makerspace and has used the scientific inquiry process.	Stickies, paper/pencils, big paper, software
Need for Accommodation	Medium	I will be working with the District Green Team Leader and District STEM Supervisor.	Some form of storyboarding either drawing or collage
Design Space	Highly specific	Decide how to collect data and what data to collect from Citizen Science Garden.	Stickies to collaborate and combine with scientific inquiry process
Maturity of Design	Early stage	The group will participate in the design from the beginning stages.	Observation of physical space, white board, and stickies to discuss likes and dislikes of other citizen science apps, such as Project Noah and Project Squirrel
Cost	Low	Paper and sticky notes.	
Portability	High	Easy to carry from classroom to classroom or outdoors, as needed.	
Technology	Medium/high	Introduce software for wireframing and basic prototyping.	
Physical Interaction	Medium/low	For the most part, students will sit and draw or work on computers.	

PBS DESIGN Squad

The PBS DESIGN Squad (2017) created lesson plans for leading student design groups. The phases are Identify Problem – Brainstorm – Design – Build (Test, Evaluate/Redesign) – Share Solution. I modified the segments into broader categories for more flexibility: Research (Identify Problem and Brainstorm), Design, Build/Prototype, Test, Revise.

The lesson plans included scripted questions to ask students before and after each phase of the design process. In addition to the suggested questions I added two reflective questions, as suggested by Barendregt et al. (2016b). The authors found that participants' solutions to the design problem benefited from allowing a moment of reflection on the design process.

Montessori Method

For child-centered learning to occur, there can be no design leader. In this study, I took on the role of Montessori Teacher. In Montessori the role of the teacher is to "guide the child without letting him/her feel the teacher's presence too much. The teacher is ready to supply desired help, but may never be the obstacle between the child and his experience" (Montessori, 1965).

Five basic principles frame the philosophy's core: respect for the child, the absorbent mind, sensitive periods, the prepared environment, and autoeducation (Morrison, 2009). I applied the five basic principles of Montessori Education to the activities I planned.

1. Respect for the child – Each child was given an assent form to choose to participate in the design project. Before each design session the students were reminded that they had the option of not participating.
2. The absorbent mind – The children differed in grade levels and their understanding of the subject matter and activities. The activities allowed children to complete each to the best of their abilities and understanding.
3. Sensitive periods – Working in small groups, the children compensated for lower skills by sharing tasks. When one student was unready to comprehend or complete one part of the design, another was.
4. The prepared environment – Activities were prepared with attention to differing skills so each activity could be completed on a scale of refinement. There were no indicators that an activity had a "right" way or that a finished product was expected.
5. Autoeducation – I observed the children working and gave minimal direction.

Learning Outcomes and 21st Century Skills

Learning outcomes are the expected results for every lesson a teacher presents to students. State education departments dictate them. The New Jersey Department of Education also requires public schools to include 21st century skills in their curriculums. The 21st century skills supported in this study were

- Collaboration
- Communication
- Global Citizen

- Information Literate Researcher
- Self-Directed Learner
- Creative & Practical Problem Solver

Each of the above was represented in some portion of the design process, if not in every phase.

Chapter 3: Bartle School Design Team

Results

The study was carried out at Bartle Elementary School, Highland Park, NJ. Bartle School has three gardens on its grounds and has an active Green Team composed of volunteer teachers, parents, and administrative staff. The school was awarded Bronze status by Sustainable New Jersey, a non-profit group dedicated to helping institutions become environmentally friendly. The problem space addressed by this project was how to make the gardens more interactive and accessible to students, teachers, and the community. Ideas included a citizen science app and interactive garden signage and displays. With both the time and material limits, we decided to focus our efforts on creating a Citizen Science Portal which can be easily coded into a responsive web CMS like WordPress.

In the planning stages the project was approved to be included in the 4th Grade enrichment program, meaning that design sessions would be part of the school day and require learning outcomes. However, due to a last-minute scheduling conflict the project was moved to an after school time slot. The school suggested we accept applications for the project in case a large number of students wanted to participate. Then we could pick names at random.

We received over twenty applications from 4th and 5th graders. I picked eleven names at random, with the thought that some students may decide to drop out of the project. Of the eleven, eight students participated consistently over the nine-week project.

Halfway through the project the group of eight was divided into four teams. Each two-student team designed and produced an interactive prototype by the end.

The sections below are a summary of each design session, it's activities, examples of student work, and description of framework.

Research (Identify the Problem and Brainstorm) – Sessions 1 & 2

In the first session we discussed the problem space of citizen science, including how to balance data collection and sharing functions within the local community as well as the scientific community. In our first session, the students heatedly discussed how to measure the success of the final design. Success, they decided, would best be measured by tracking the number of photos posted by users. One student, though, voiced a problem with this metric, observing that "photos won't be a good way to tell, because not everyone will upload photos." He concluded, "[A] counter is better." The students ended the session by creating mood boards, which allowed them to visually explore what they wanted users to see, feel, and do while using the portal.

During the second session students created personas. First, they sketched the persona's traits on paper. Then, as a hands-on activity they transformed the 2D persona into a 3D wooden figure and a diorama of a landscape. The students dove happily into their imaginations to create people they envisioned using the portal. One child, reflecting on the different personas being created, noted that the students would have to design a portal that could be used by anyone, including "kids, teenagers, young adults, adults, and old adults like 75." Some students created complex personas, by not only imagining the hobbies of their fictional people but by also considering relationships that might affect a user's interaction with the garden and the portal. One student asked, "What if his wife likes gardening but he doesn't? Is that important?" while creating his persona, "Stanley" a 75-year-old male. This initiated a group discussion about the necessary traits to include in a persona. After the discussion some students added more details, while others kept personas with minimal details, as evidenced by one student's persona of a teenage girl: a sketch of a long-haired girl sitting on an oversized chair and completely engrossed in her cellphone. The text underneath read, "She's on social media all the time."

The activities in the first two sessions encompassed the seven 21st century skills tracked in this study, especially Communication and Information Literate Researcher skills. In accordance with the Montessori Method, students completed their personas to the levels of their abilities. Some were able to empathize with their personas and to communicate empathy by giving much forethought to design through those personas. Other students left their persona descriptions on a more basic level. Because the students were working in groups, gaps in skills were filled inconspicuously. Science and Engineering learning outcomes ("Science and the Engineering Practices Grades 3-5 Quick Reference," 2017) assigned to the Research Phase were

1. Asking Questions and Defining Problems
2. Obtaining, Evaluating, and Communicating Information

Reflection – Research Phase

All students were given an opportunity to reflect on the Research Phase of the design process; they were asked, “How was the research process for you? What was your favorite part?”

Answers included

“It was fun pretending to be someone else.”

“I felt like I could do anything I wanted.”

“I liked the dioramas because we got to use clay.”

“We got to use our creative mind and build stuff.”

“It helped me envision like what the person would want to do.”

None of the students believed the Research Phase was similar to work done in class.

Figure 1. Mood boards. Photo of students creating collage mood boards.

Figure 2. Dioramas. Photo of student diorama representing her persona in the school garden.

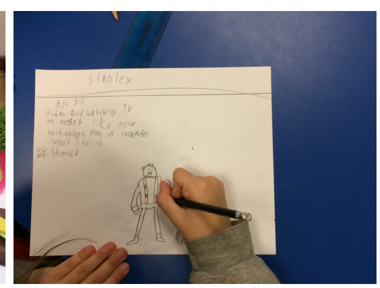

Figure 3. Persona. Photo of student sketching his persona, “Stanley.”

Design – Sessions 3 & 4

With a grasp of the diverse needs of their audience, the students brainstormed as to the features the portal should offer. Each chose a feature or a task, sketched out a flow, and shared his/her ideas with the group. Then students with similar tasks paired up to combine their work into a single interactive flow.

Reflection – Design Phase

All students were given an opportunity to reflect on the Design Phase of the process; they were asked, “What goals are we trying to achieve with our design?” Answers included

“Cool to show how people will learn about the garden and what they can do in it.”

During the reflection portion of the session, the group went off on a tangent to discuss moderating user-submitted photos. The students wanted to design something where no “bad” photo was ever uploaded to the portal. One student suggested that other portal users be the moderators and flag inappropriate content. But some students argued that having inappropriate content posted even for a few minutes is harmful; conceivably someone could see the photo. The group agreed that in the future moderators would have to be appointed as gatekeepers for photo uploads.

Another tangent was a heated discussion of the types of games that would be appropriate for the portal. Two teams had created sketches of environmentally based games. One was a market game where players planted, grew, and harvested crops to sell in a community market. The other game, however, included cutting down trees and stealing wood from other players to build houses. The majority suggested that the second team change the objective of its game so that players were rewarded for sustainable tree harvesting instead. They also ruled that there should be no stealing games available on the portal.

These discussions required little direction on my part. They were child led as preferred in the Montessori Method. In addition, through the game ethics debate, the students exhibited not only collaboration, but other 21st century skills, like Creative & Practical Problem Solving and even Global Citizen Skills, as evidenced by the sustainable forestry suggestion. Science and Engineering learning outcomes ("Science and the Engineering Practices Grades 3-5 Quick Reference," 2017) assigned to the Design Phase were

1. Asking Questions and Defining Problems
2. Developing and Using Models

Figure 4. Sketching task flows. Photo of two students sketching their combined task flow.

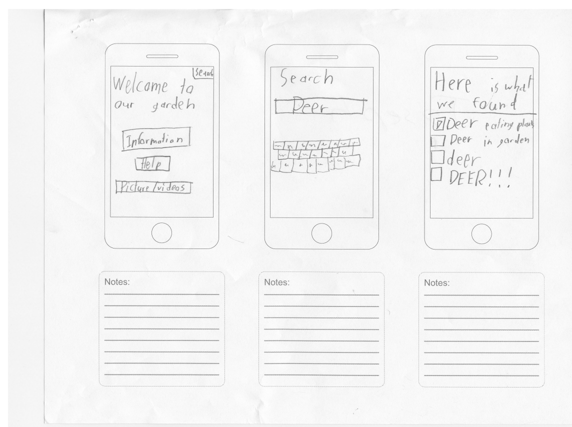

Figure 5. Sketch of screen flow. Photo of screens for photo search feature.

Build/Prototype – Sessions 5, 6, & 7

In the fifth session the teams combined their task flows into a rough paper prototype that they tested informally with each other.

Then I introduced the students to Balsamiq, because it is a simple prototyping tool with an easy-to-use interface and process for adding interactions. The team member who manipulated the software fastest automatically became the one to transfer the team's paper prototype into digital form. While creating the digital wireframes, teams revised their designs and asked questions of other teams.

Once the wireframes were completed, the teams added interactions. Two teams had no difficulty adding interactions, while the other two struggled. One team exhibited critical thinking when tasked with creating the same interaction 20xs on one page. I explained that in a prototype not every element must be clickable if the same repetitive interaction was exhibited on other elements. It's a universal process. One teammate, in a burst of understanding, exclaimed, "Oh, it's not specific. Like this stands in for something. You don't have to connect all the parts each time again."

The 21st century skills used in the Build/Prototype Phase were collaboration, communication, and self-directed learning. This phase embodies much of the Montessori Method for absorbent mind and sensitive periods. For instance, students were able to contribute to their team at their comfort level for wireframing, interactions and software manipulation. During this phase, the students not only helped each other, but also challenged and redirected one another. The prototyping stage demonstrated the need for a prepared environment geared toward learning and autoeducation. Science and Engineering learning outcomes ("Science and the Engineering Practices Grades 3-5 Quick Reference," 2017) assigned to the Build/Prototype Phase were

1. Developing and Using Models
2. Constructing Explanations and Designing Solutions

Reflection – Build/Prototype Phase

All students were given an opportunity to reflect on the Build/Prototyping Phase; they were asked, "How was the Prototyping Stage for you? What was your favorite part?"

Answers included

> "I liked it. It serves a purpose."
>
> "We actually got to create something."
>
> "It was hands-on. I liked it the most."

Again, when asked if this stage reminded them of any work done in class all the students said no.

Figure 6. Paper to digital. Photo of students translating their paper design to digital prototype.

Figure 7. Interactions. Photo of students adding interactions into their digital prototype, using Balsamiq.

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Test – Session 8

In user testing, students asked teachers, other students, and family members to test their prototypes. The student design teams struggled to keep quiet and simply observe the users' actions. Many engaged in discussions during the testing. The teams were successful in tasking one partner as the note taker and the other the host. All teams said they enjoyed sharing their prototypes, although teams that tested game prototypes seemed to experience some frustration, because their prototypes were not fully functioning games. They had to explain this to every participant.

The testing stage aligned well with the Montessori Method in being child-directed. It also aligned well with 21st century skills, Creative & Practical Problem Solving, and Communication. Student designers had to observe how each participant interacted differently with their prototype. Each team had no more than eight participants test its prototype. Science and Engineering learning outcomes ("Science and the Engineering Practices Grades 3-5 Quick Reference," 2017) assigned to the Testing Phase were

1. Developing and Using Models
2. Planning and Carrying Out Investigations

Reflection – Testing Phase

All students were given an opportunity to reflect on the Testing Phase of the process; they were asked, "How was the Testing Stage for you? What was your favorite part?"

Answers included

> "It was fun, because we got to ask real people who were not involved in the app."
>
> "I liked explaining to them and writing down the feedback."
>
> "Interesting feedback from people not involved in the design."

This was the only stage that reminded some students of work done in class. One student compared user testing to English class in which, "We work with partners to get feedback on our writing to see if it's good."

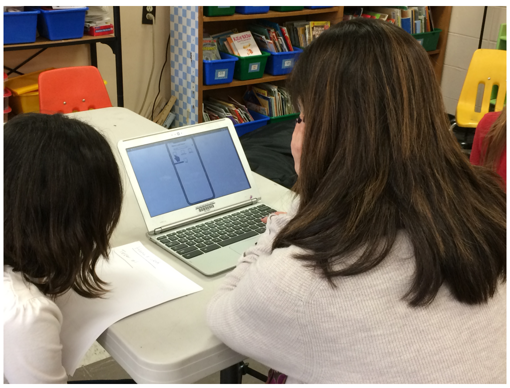

Figure 8. Testing day. Photo of user testing.

Figure 9. Testing day. Photo of user testing.

Revise – Session 9

In our last session we reviewed the observations and comments from Testing Day. Students responded that they enjoyed the Testing Phase but were tired of working on their prototypes. We used stickies to map out the revisions needed for the next iteration. Students were excited by the prospect of adding more features to their final product. They wanted to build and code the portal, rather than iterate and test again.

The Revise stage aligned with the Montessori Method in being child-directed, as the group discussed what features should be changed. This stage also aligned with 21st century skills, especially Creative & Practical Problem Solving, Collaboration, and Communication. Science and Engineering learning outcomes ("Science and the Engineering Practices Grades 3-5 Quick Reference," 2017) assigned to the Revise Phase were

1. Analyzing and Interpreting Data
2. Using Mathematics and Computational Thinking
3. Engaging in Argument from Evidence

Reflection – Revise Phase

All students were given an opportunity to reflect on the Revise Phase of the process; they were asked, "How was the Revise Phase for you? What was your favorite part?"

Answers included

"I'm tired. Want to build something and then fix it afterwards."

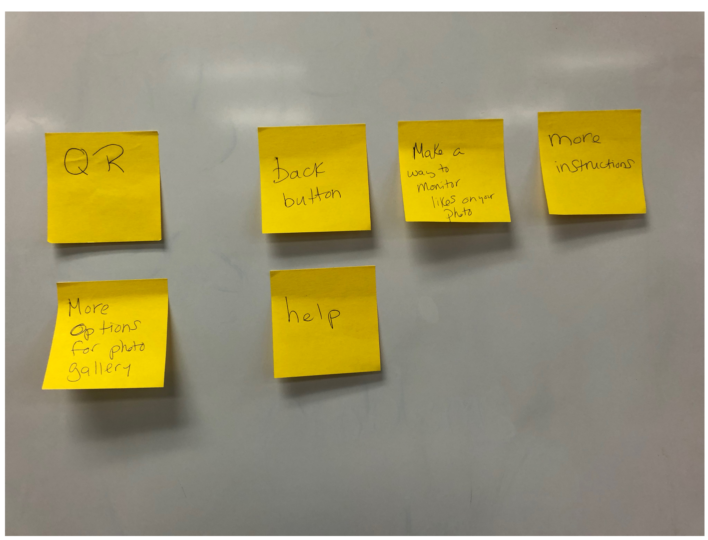

Figure 10. Testing day results. Photo of sticky notes used to organize feedback from user testing.

Table 3

Design session lessons, activities, and learning outcomes

Session	Lesson	Activity	Montessori Method	Learning Outcomes
Week 1 (Research)	Discussion of problem space, research problem space, and brainstorming solutions	Stickies, Mood boards	1. Absorbent Mind 2. Sensitive Periods	1. Asking Questions and Defining Problems 2. Obtaining, Evaluating & Communicating Information 3. Communication 4. Information Literate Researcher
Week 2 (Research)	Discussion of potential users	Stickies, personas, dioramas	1. Absorbent Mind 2. Sensitive Periods	1. Asking Questions and Defining Problems 2. Obtaining, Evaluating & Communicating Information 3. Communication 4. Information Literate Researcher
Week 3 (Design)	Brainstorming tasks/functions, initial sketches	Stickies, Mood boards	1. Absorbent Mind 2. Sensitive Periods 3. Autoeducation	1. Asking Questions and Defining Problems 2. Developing and Using Models 3. Collaboration 4. Creative and Practical Problem Solving 5. Global Citizen Skills

Session	Lesson	Activity	Montessori Method	Learning Outcomes
Week 4 (Design)	Pair up and combine task flows. Share and discuss	Template paper, pencils	1. Absorbent Mind 2. Sensitive Periods 3. Autoeducation	1. Asking Questions and Defining Problems 2. Developing and Using Models 3. Collaboration 4. Creative and Practical Problem Solving 5. Global Citizen Skills
Week 5 (Build/Prototype)	Paper prototype. Informal testing	Template paper, pencils	1. Sensitive Periods 2. Autoeducation 3. Prepared Environment	1. Developing and Using Models 2. Constructing Explanations and Designing Solutions 3. Collaboration 4.Communication 5. Self-Directed Learning
Week 6 (Build/Prototype)	Digital prototyping	Chromebooks, Balsamiq Cloud	1. Sensitive Periods 2. Autoeducation Prepared Environment	1. Developing and Using Models 2. Constructing Explanations and Designing Solutions 3. Collaboration 4.Communication 5. Self-Directed Learning

Session	Lesson	Activity	Montessori Method	Learning Outcomes
Week 7 (Build/Prototype)	Digital prototyping	Chromebooks, Balsamiq Cloud	1. Sensitive Periods 2. Autoeducation 3. Prepared Environment	1. Developing and Using Models 2. Constructing Explanations and Designing Solutions 3. Collaboration 4.Communication 5. Self-Directed Learning
Week 8 (Testing)	User testing	Chromebooks, Balsamiq Cloud, volunteers	1. Autoeducation	1. Developing and Using Models 2. Planning and Carrying Out Investigations 3. Creative and Practical Problem Solving 4.Communication
Week 9 (Revise)	Revise	Chromebooks, Balsamiq Cloud, stickies	1. Autoeducation	1. Analyzing and Interpreting Data 2. Using Mathematics and Computational Thinking 3. Engaging in Argument from Evidence 4. Collaboration 5.Communication 6. Creative and Practical Problem Solving

Note. Learning outcomes taken from Science and Engineering Practices Grades 3-5 ("Science and the Engineering Practices Grades 3-5 Quick Reference," 2017) and 21st Century Standards ("New Jersey Student Learning Standards: 21st Century Life and Careers," 2017).

Limitations

This study was limited by its size and scope. In the planning stages the study was approved as an addition to the enrichment program in which sessions were to be held during the school day. The implications of this was that the design process is a legitimate addition or complement to public school curriculum and educational philosophies. Unfortunately, because of staffing issues, the study had to be moved to after school where parents signed-up their children voluntarily. Therefore, the student group was populated by children who were already interested in technology and design or whose parents were. The study could not address the design process across the school curriculum regardless of prior interest. In addition, the size of the study group was limited. Classroom sized groups would have to be observed to test if the model is scalable within the structure of the school day.

Chapter 4: Bringing Design Projects to Public Schools

Conclusions and Future Work

The combination of frameworks and teaching methods explored in this study offers a way for PD practitioners to introduce design activities into a public school setting. It is unique in its wide scope, ranging from planning activities and preparing materials to assigning learning outcomes and choosing a teaching method or style. The combination of frameworks is versatile for use by both PD practitioners who want to learn how to frame a design project in a public school setting, as well as teachers who want to teach lessons through PD. Regardless of professional training, instructors can use this method to deliver well-rounded design projects.

First, the FACIT PD Framework (Walsh, et al., 2013) acts as a guide for novice designers or for PD practitioners who have never worked with children. It is an easy-to-share template if the project is a collaborative effort. The framework can be included in proposals to school boards or school administrations to clarify materials needed and the general scope of students' involvement in the project.

The second helpful aspect of the study's framework is defining an educational philosophy that enhances PD methods. In a constructivist educational philosophy like the Montessori Method, a PD leader must create design activities that are child-centric and open-ended. For instance, while considering the persona activity for the study's project, I did not lock myself and the children into a typical, results-driven pencil on paper persona. Were that the single activity it would have excluded children who lacked written language skills. With the addition of a 3D diorama and a persona, children without developed written language skills could fully explore their personas in a creative and tactile way. The design activity allowed for individual exploration of a persona within a student's skillset, exemplifying Montessori's idea of sensitive periods.

Critical to the acceptance of design projects in school is the ability to assign learning outcomes to child-centric, open-ended activities. Pioneered by Druin's (1999) research, PD practitioners need only go one step further to look at their state's educational websites for listings of curriculum standards. For this project, the NJ Department of Education website not only provided a list of the subject-specific NJ Science & Engineering standards, but also a core list of 21st century skills. Those modern skills are easiest to assign to design activities, especially for PD practitioners without a teacher for collaboration.

However, more than simply adding another framework to the PD literature, the study suggests that the Montessori Method and citizen science combine to create a co-design experience. Co-design is a "subset of PD in which expert designers work with the target audience to solve a problem" (Walsh, et al., 2013). Throughout the study the end-user, student, and teacher were included in the design process making them active participants in solving their problem.

The Montessori Method fits well within the definition of co-design in that Montessori teachers are not directive task masters, but rather participants alongside their students within the learning process. The student and teacher co-design the learning process and educational experiences throughout the student's journey in a Montessori classroom. It is a partnership.

Citizen science by its very nature also fits well within the domain of co-design. It offers different levels of participation, from pure data collection and sharing to interaction with the data. The students in this study investigated how they thought end users, including themselves, would want to interact with the portal and offered multiple ways to do so. They developed different processes for users to share data and to interact with the data and each other. For example, one team developed features for users to share photos, identify wildlife in posted photos, and create a field guide gallery highlighting "most commonly seen" wildlife. Social media "like" options were added by another group. All of these features offered users different levels of interaction with each other and the data. The portal design became the blueprint for more than crowd-sourced data, becoming an interactive process with which users could shape their own journey. In this way citizen science and the Montessori Method share a common philosophical thread based in constructivist theory where everyone involved is a co-designer.

In a public school setting the proposed combination of frameworks can assist teachers throughout the planning of a co-design project. To begin teachers might hold brainstorming sessions with colleagues and administrators to identify community or school-based citizen science projects. After the problem space is identified, teachers can again use the study's combination of frameworks to plan activities and assign learning outcomes. These can be presented to a school or curriculum board for approval: the final hurdle to offering design-based learning experiences.

Ultimately the main obstacle to adopting co-design citizen science projects based on the Montessori Method is a public school's structure of regulations and testing that often preclude child-centric, progressive lessons. There is a complicated balance between state regulations, district initiatives, and school policies. As the study has shown, design projects are compatible with both constructivist educational philosophies and technology-based state curriculum standards. Student interest remained high throughout the project. Students were engaged and enthusiastic from the first session to the last. And while there are many PD frameworks available, this study provides PD practitioners and teachers a roadmap to creating a comprehensive co-design project. With careful planning of the learning environment and attention to creative activities, the combination of these frameworks offers an avenue to modern, hands-on educational projects that incorporate curricular demands.

References

BADA, Dr. & Olusegun (2015). Constructivism learning theory: A paradigm for teaching and learning. *IOSR Journal of Research & Method in Education, 5*(6), 66-70.

Barendregt, W., Bekker, M. M., Börjesson, P., Eriksson, E., & Torgersson, O. (2016a). The role definition matrix: Creating a shared understanding of children's participation in the design process. *Proceedings of the The 15th International Conference on Interaction Design and Children* (pp. 577–582). New York, NY, USA: ACM. https://doi.org/10.1145/2930674.2935999

Barendregt, W., Bekker, T. M., Börjesson, P., Eriksson, E., & Torgersson, O. (2016b). Legitimate participation in the classroom context: Adding learning goals to participatory design. *Proceedings of the The 15th International Conference on Interaction Design and Children* (pp. 167–174). New York, NY, USA: ACM. https://doi.org/10.1145/2930674.2930686

Constructivism as a paradigm for teaching and learning. (2017, December 5). Retrieved from https://www.thirteen.org/edonline/concept2class/constructivism/index_sub1.html

Derboven, J., Van Mechelen, M., & Slegers, K. (2015). Multimodal analysis in participatory design with children: A primary school case study. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 2825–2828). New York, NY, USA: ACM. https://doi.org/10.1145/2702123.2702475

DESIGN SQUAD. The design process | PBS KIDS GO! (December 5, 2017). Retrieved from http://pbskids.org/designsquad/parentseducators/workshop/process.html

Druin, A. (1999). Cooperative inquiry: Developing new technologies for children with children. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 592–599). New York, NY, USA: ACM. https://doi.org/10.1145/302979.303166

Eveleigh, A., Jennett, C., Blandford, A., Brohan, P., & Cox, A. L. (2014). Designing for dabblers and deterring drop-outs in citizen science. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2985–2994). New York, NY, USA: ACM. https://doi.org/10.1145/2556288.2557262

Frauenberger, C., Good, J., & Keay-Bright, W. (2010). Phenomenology, a framework for participatory design. *Proceedings of the 11th Biennial Participatory Design Conference* (pp. 187–190). New York, NY, USA: ACM. https://doi.org/10.1145/1900441.1900474

Frauenberger, C., Good, J., Keay-Bright, W., & Pain, H. (2012). Interpreting input from children: A designerly approach. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2377–2386). New York, NY, USA: ACM. https://doi.org/10.1145/2207676.2208399

Horton, M., Read, J. C., Mazzone, E., Sim, G., & Fitton, D. (2012). School friendly participatory research activities with children. *CHI '12 Extended Abstracts on Human Factors in Computing Systems* (pp. 2099–2104). New York, NY, USA: ACM. https://doi.org/10.1145/2212776.2223759

Hourcade, J. P., Bederson, B. B., Druin, A., & Taxén, G. (2002). KidPad: Collaborative storytelling for children. *CHI '02 Extended Abstracts on Human Factors in Computing*

Systems (pp. 500–501). New York, NY, USA: ACM. https://doi.org/10.1145/506443.506449

ISTE - International Society for Technology in Education. (2017, December 5). Retrieved from https://www.iste.org/

Iversen, O. S., Smith, R. C., & Dindler, C. (2017). Child as protagonist: Expanding the role of children in participatory design. *Proceedings of the 2017 Conference on Interaction Design and Children* (pp. 27–37). New York, NY, USA: ACM. https://doi.org/10.1145/3078072.3079725

Kolodner, Janet L. (2002). Facilitating the learning of design practices: Lessons learned from an

inquiry into science education. *Journal of Industrial Teacher Education, 39*(3).

Kuure, L., Halkola, E., Iivari, N., Kinnula, M., & Molin-Juustila, T. (2010). Children imitate!: Appreciating recycling in participatory design with children. *Proceedings of the 11th Biennial Participatory Design Conference* (pp. 131–140). New York, NY, USA: ACM. https://doi.org/10.1145/1900441.1900460

Kuznetsov, S. (2013). Expanding our visions of citizen science. *Interactions*, *20*(4), 26–31. https://doi.org/10.1145/2486227.2486234

Landoni, M., Rubegni, E., Nicol, E., & Read, J. (2016). How many roles can children play? *Proceedings of the The 15th International Conference on Interaction Design and Children* (pp. 720–725). New York, NY, USA: ACM. https://doi.org/10.1145/2930674.2932222

Landry, P., Parés, N., Minsky, J., & Parés, R. (2012). Participatory design for exertion interfaces for children. *Proceedings of the 11th International Conference on Interaction Design and Children* (pp. 256–259). New York, NY, USA: ACM. https://doi.org/10.1145/2307096.2307139

Large, A., Nesset, V., Beheshti, J., & Bowler, L. (2006). "Bonded design": A novel approach to intergenerational information technology design. *Library & Information Science Research, 28 (1), 64-82.*

Laughnan, J. (2004). The organization of inventing and prototyping activities with children as design partners. *Proceedings of the 2004 Conference on Interaction Design and Children: Building a Community* (pp. 127–128). New York, NY, USA: ACM. https://doi.org/10.1145/1017833.1017854

Lillard, Paula Polk. *Montessori, a modern approach*. New York: Schocken Books, 1972.

Mazzone, E., Iivari, N., Tikkanen, R., Read, J. C., & Beale, R. (2010). Considering context, content, management, and engagement in design activities with children. *Proceedings of the 9th International Conference on Interaction Design and Children* (pp. 108–117). New York, NY, USA: ACM. https://doi.org/10.1145/1810543.1810556

Mazzone, E., Read, J. C., & Beale, R. (2011). Towards a framework of co-design sessions with children. *Human-Computer Interaction – INTERACT 2011* (Vol. 6949, pp. 632–635). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-23768-3_100

McNally, B., Guha, M. L., Mauriello, M. L., & Druin, A. (2016). Children's perspectives on ethical issues surrounding their past involvement on a participatory design team. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 3595–3606). New York, NY, USA: ACM. https://doi.org/10.1145/2858036.2858338

McNally, B., Mauriello, M. L., Guha, M. L., & Druin, A. (2017). Gains from participatory design team membership as perceived by child alumni and their parents. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (pp. 5730–5741). New York, NY, USA: ACM. https://doi.org/10.1145/3025453.3025622

Montessori, M. (1965). *Dr. Montessori's own handbook*. New York: Schocken Books.

Morrison, G.S. (2009). *Early Childhood Education Today* (pp. 140-143).

Mugar, G., Østerlund, C., Jackson, C. B., & Crowston, K. (2015). Being present in online communities: Learning in citizen science. *Proceedings of the 7th International Conference on Communities and Technologies* (pp. 129–138). New York, NY, USA: ACM. https://doi.org/10.1145/2768545.2768555

New Jersey student learning standards: 21st century life and careers. (2017, December 5). Retrieved from http://www.state.nj.us/education/aps/cccs/career/

Papert, S. (1993). *Mindstorms: children, computers, and powerful ideas* (2nd ed.). New York: Basic Books.

Qaurooni, D., Ghazinejad, A., Kouper, I., & Ekbia, H. (2016). Citizens for science and science for citizens: The view from participatory design. *Proceedings of the 2016 CHI*

Conference on Human Factors in Computing Systems (pp. 1822–1826). New York, NY, USA: ACM. https://doi.org/10.1145/2858036.2858575

Radchenko, I., & Maksimenkova, O. (2016). Principles of citizen science in open educational projects based on open data. *Proceedings of the 12th Central and Eastern European Software Engineering Conference in Russia* (pp. 5:1–5:5). New York, NY, USA: ACM. https://doi.org/10.1145/3022211.3022216

Read, J. (2015). Children as participants in design and evaluation. *Interactions*, *22*(2), 64–66. https://doi.org/10.1145/2735710

Read, J. C. (2009). Warp speed design: A rapid design method for use with children. *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (pp. 4681–4686). New York, NY, USA: ACM. https://doi.org/10.1145/1520340.1520720

Read, J. C., Fitton, D., & Horton, M. (2014). Giving ideas an equal chance: Inclusion and representation in participatory design with children. *Proceedings of the 2014 Conference on Interaction Design and Children* (pp. 105–114). New York, NY, USA: ACM. https://doi.org/10.1145/2593968.2593986

Reeves, N., Tinati, R., Zerr, S., Van Kleek, M. G., & Simperl, E. (2017). From crowd to community: A survey of online community features in citizen science projects. *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing* (pp. 2137–2152). New York, NY, USA: ACM. https://doi.org/10.1145/2998181.2998302

Sanders, E.B.-N., Brandt, E., & Binder, T. (2010). A Framework for Organizing the Tools and Techniques of Participatory Design. *Proceedings of the 11th Biennial Participatory Design Conference*, 195–198. PDC '10. New York, NY, USA: ACM. https://doi.org/10.1145/1900441.1900476

Scaife, M., Rogers, Y., Aldrich, F., & Davies, M. (1997). Designing for or Designing with? Informant Design for Interactive Learning Environments. *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems*, 343–350. CHI '97. New York, NY, USA: ACM. https://doi.org/10.1145/258549.258789

Science and the Engineering Practices Grades 3-5 Quick Reference. (2017, December 5). Retrieved from http://www.state.nj.us/education/aps/cccs/science/resources/QR35.pdf

Tinati, R., Luczak-Roesch, M., Simperl, E., & Hall, W. (2016). Because science is awesome: Studying participation in a citizen science game. *Proceedings of the 8th ACM Conference on Web Science* (pp. 45–54). New York, NY, USA: ACM. https://doi.org/10.1145/2908131.2908151

Van Mechelen, M., Gielen, M., vanden Abeele, V., Laenen, A., & Zaman, B. (2014). Exploring challenging group dynamics in participatory design with children. *Proceedings of the 2014 Conference on Interaction Design and Children* (pp. 269–272). New York, NY, USA: ACM. https://doi.org/10.1145/2593968.2610469

Van Mechelen, M., Zaman, B., Laenen, A., & Abeele, V. V. (2015). Challenging group dynamics in participatory design with children: Lessons from social interdependence theory. *Proceedings of the 14th International Conference on Interaction Design and*

Children (pp. 219–228). New York, NY, USA: ACM. https://doi.org/10.1145/2771839.2771862

Vattam, S. S., & Kolodner, J. L. (2006). Design-based science learning: Important challenges and how technology can make a difference. *Proceedings of the 7th International Conference on Learning Sciences* (pp. 799–805). Bloomington, Indiana: International Society of the Learning Sciences. Retrieved from http://dl.acm.org/citation.cfm?id=1150034.1150150

Walsh, G. (2009). Wii can do it: Using co-design for creating an instructional game. *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (pp. 4693–4698). New York, NY, USA: ACM. https://doi.org/10.1145/1520340.1520722

Walsh, G. (2013). Anatomy of a design session. *Interactions*, *20*(6), 68–71. https://doi.org/10.1145/2517669

Walsh, G., Foss, E., Yip, J., & Druin, A. (2013). FACIT PD: A framework for analysis and creation of intergenerational techniques for participatory design. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2893–2902). New York, NY, USA: ACM. https://doi.org/10.1145/2470654.2481400

Xu, D., Read, J. C., Sim, G., & McManus, B. (2009). Experience it, draw it, rate it: Capture children's experiences with their drawings. *Proceedings of the 8th International Conference on Interaction Design and Children* (pp. 266–270). New York, NY, USA: ACM. https://doi.org/10.1145/1551788.1551849

Yip, J., Clegg, T., Bonsignore, E., Gelderblom, H., Rhodes, E., & Druin, A. (2013). Brownies or bags-of-stuff?: Domain expertise in cooperative inquiry with children. *Proceedings of the 12th International Conference on Interaction Design and Children* (pp. 201–210). New York, NY, USA: ACM. https://doi.org/10.1145/2485760.2485763