only to inspire solutions for authentic problems, but also to inform the testing and refinement of the design itself [24].

Within the context of a makerspace, design thinking enables students to grapple with authentic, everyday problems, and create thoughtful solutions in response [9]. In doing so, they exercise positive risk-taking and creativity [25], the ability to direct and prioritize their own learning [10], as well as critical thinking, perseverance, and digital literacy skills [11]. The design thinking process also promotes "mindfulness of process" [24] or metacognitive awareness [27] as students continuously evaluate their biases and others' perspectives through ongoing documentation, design walk-throughs and constructive external or reflective feedback.

2.3. Passion-Based Learning

Utilizing students' personal interests as a vehicle for learning is harmonious with the inquiry-driven nature of the makerspace [22]. Expanding upon Papert's [9] conceptualization of contexts with "low floors and high ceilings", Resnick and colleagues [12] recommended the addition of "wide walls" that would accommodate a variety of interests, recognizing the value of personally-relevant educational experiences. Not only are students more likely to remain engaged by an activity that integrates a topic of interest [28], they may also benefit from enhanced creativity [29] and other global competencies [20], and a deeper understanding of the concepts being learned [17].

Seely Brown and Adler [13] encapsulate the role of passion-based learning in modern education, asserting that finding something "that ignites a student's passion can set the stage for the student to acquire both deep knowledge about a subject ('learning about') and the ability to participate in the practice of a field through productive inquiry and peer-based learning ('learning to be')" (p.28).

3. Methodology

3.1. Setting

This study was conducted during a March break camp at the STEAM-3D Maker Lab in the Faculty of Education at Ontario Tech University. The camp lasted for five days, with four full days devoted to our research. Participants were selected on a first-registered basis. Three research assistants were actively involved in facilitating the maker camp activities and documenting ongoing field observations. Additionally, six teacher and teacher candidate volunteers were available to assist during various group activities and development of participants' IoT passion projects. The STEAM-3D Maker Lab at Ontario Tech University was established under Dr. Janette Hughes, Canada Research Chair in Technology and Pedagogy, to conduct educational research associated with maker pedagogies, digital literacies and the effective integration of technology and pedagogy.

3.2. Participants

The STEAM-3D maker camp involved 17 local participants aged 7 to 14 years with a mean age of 10 years. There was a maximum of 17 campers to ensure effective guidance and facilitation from the three research assistants. Participants had a nearly even distribution of genders: nine males and eight females. Ten participants were familiar with each other either as siblings, extended family members, classmates or friends. These participants tended to work together during early camp group activities however, only two of these familiar participants created their IoT passion project together. Previous experience with technology was not required, therefore participants varied in both experience and knowledge with different technologies and computing competencies.

3.3. Research Design

The maker camp was designed to accommodate two different research objectives: our IoT-themed passion projects and another related to girls' development of STEM identities. To answer our research questions, we used a constructionist, guided inquiry approach to introduce basic IoT concepts, technologies and designs with daily design themes and reflection prompts to guide participants' development of their IoT passion projects. Learning activities were structured to have participants focus on discovery and design with regular physical and mental technology breaks to avoid fatigue and over-exposure. Daily design themes were introduced with a "word of the day", group discussions, stories, videos and reinforced with daily reflective, online journals with prompting questions. Participants' IoT designs were encouraged to be socially conscious and problem-solving for either individual or community. Campers were given full freedom in their IoT designs, however, their prototypes and final models were limited by their four-day work period and the available IoT toolkits which included littleBits, micro:bit, and Arduino Uno with access to additional sensors and actuators. Therefore, many designs were at a rudimentary level of IoT - exploring systems with sensors, interconnectivity, and possible extensions to data collection and management systems. Research assistants acted as camp facilitators, providing guidance on IoT technologies, concepts and designs on one-on-one or small group basis within the IoT passion project work periods.

4. Data Collection & Analysis

The study began with a self-reported online pre-study questionnaire featuring 23 open-ended questions. As the camp encompassed two distinct research goals, only 6 questions related to participants' understanding of IoT, their experience with IoT and other technologies, and thoughts on school subjects, STEM, and social justice were collected for this paper. The remaining questions asked about demographics (n=4) or topics specific to the second research study (n=13). An online application, Seesaw, was employed as a digital design journal to collect participants' project planning and process work, as well as reflections at the end of each day. Participants were prompted with questions aligned to design and/or IoT themes, such as:

- What did you discover about the Internet of Things (IoT) today?
- Why did you choose your project and/or goal for the week?
- What are your 'next steps' for your invention? Are there any other maker tools that would help?

Drawing upon the multimodal affordances of the platform, participants' responses contained writing, images, videos, audio, or some combination of these. Examples of students' design journal entries can be seen below in Figure 1.

Figure 1. Examples of students' multimodal digital design journal entries.

They also documented their IoT passion project brainstorming and design ideas using Popplet, an online mind mapping application. Finally, throughout the week, research assistants captured images and videos of informal discussions, recorded detailed field notes highlighting key insights and feedback, and video-recorded work sessions, group discussions and exit interviews which were all later transcribed.

The study was a subset of a larger, multi-layered research project during the five-day school break in March. With only four days for participants to learn, design and build their IoT passion projects, it was not possible to collect complete data sets from all participants. In total, ten full participant data sets, which included pre-surveys, brainstorming designs, reflective journal posts, and final interviews, were collected. To analyze this data, directed content analysis was used with key themes pre-defined as the initial coding schemes [30]. These preliminary coding schemes were related to themes on IoT, design processes and skill sets, passion-based learning and constructionist approaches, with additional codes emerging through subsequent rounds of analysis. The collected data provided very rich and detailed descriptions of participants' conceptual models, prototype creations, and design-thinking processes. However, to effectively explore the first research question the authors narrowed their analysis to three distinct case studies. These three cases presented unique IoT passion projects with clear social significance and conceptual designs, while their IoT creations represented the full spectrum of success: fully, partially, and unsuccessful. Our second research question involved the analysis of all collected data using directed content analysis exclusively.

5. Findings

5.1. What Happens when Participants Design an IoT Passion Project Within a Constructionist Context?

Given the role of the design process in making, we were interested in participants' naturalistic tendencies towards design in a context with few requirements or constraints. Although campers were provided with a copy of The Works Museum [31] Engineering Design Process in their digital design journals, they were encouraged to proceed however they felt most comfortable. They were given one hour and several prompting questions to begin designing their projects, after which they were free to direct their own process. For the scope of this paper, the following three cases have been selected to provide insight into a range of design decisions, work processes, and degrees of success in producing a prototype of their IoT passion projects.

Anisha & Derick's home security system

Anisha† (age 10) and Derick (age 9) formed an organic partnership; as cousins, they had a pre-established level of comfort and rapport that informed their decision to work together on a collective passion project. During their initial planning phase, they identified three areas of interest before deciding to create a home security monitoring and alarm system with facial recognition:

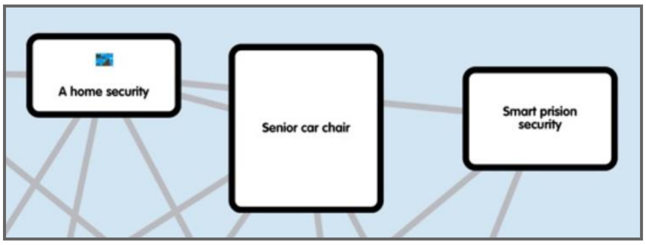

Figure 2. Anisha and Derick's passion project brainstorming.

† All names are pseudonyms.

Derick later explained that "it could help a lot of people that need a lot of security around their house," and Anisha cited issues with guns, violence, and the political climate as further inspiration. Despite being decisive in selecting the focus for their passion project, they appeared to be unsure about how to continue in the design and development process until a facilitator encouraged them to think about the technologies and physical components they would need to accomplish their goal. This prompted a discussion between the pair about integrating a motion sensor and other possible elements into their design, but these ideas were never committed into their planning document. As they prepared to move into the creation phase, their plans were rough and non-specific, describing their security system only as having "face reconision[sic] so you can take a picture of your face then you will set up a camera and when the face reconision[sic] does not reconize[sic] your face it will set an alarm."

Despite being successful in identifying a problem and beginning to design a solution, Anisha and Derick continued to have difficulty progressing with their project in the absence of dedicated guidance. Their ongoing challenges reinforce the notion that, despite literature supporting the role of passion-based learning and guided inquiry in promoting both learning and engagement [19, 28], one size does not necessarily fit all. Camp facilitators continued to assist them in refining their ideas, identifying necessary components, and getting them started in the process of constructing their initial prototypes, but were unable to provide the degree of support required to keep the pair moving towards their goal as their focus was divided between other participants. Fortunately, Anisha was able to work alongside another participant (Amalya, described below) who had created similar components for her own passion project and was able to assist the pair in constructing a 3D model to support their home security prototype.

Figure 3. Amalya and Anisha working in TinkerCAD 3D modelling software.

At one point, Derick was motivated by another participant who had been demonstrating the success she had achieved in coding her own micro:bit passion project, urging his partner, "Anisha, we need to work on this!" However, this motivation was unable to sustain their momentum, as they were quick to disengage from their project whenever they encountered difficulty and immediate support was unavailable. Interestingly, the pair opted not to utilize the daily reflection prompts that were intended to support and further develop participants' designs, which may have also impeded their progress. As a result of these challenges, Anisha and Derick were unable to produce a physical prototype of their IoT home security system.

This case illustrates the complex balance surrounding the type of inquiry employed within a makerspace. While giving young makers freedom and control over their design and making activities can sustain engagement and commitment to a task, facilitators must be conscious of their progress and offer timely support to avoid disengagement when learners are unsure how to proceed [21].

Emily's endangered species tracker

Emily's (age 9) IoT passion project was inspired by a love of animals that she shared with her brother and a close friend. This informed her design of a robot that could track and report on the status of endangered animals to better inform conservation efforts. Her digital mind map deconstructed her project into several components, including a GPS tracker, a camera with pattern recognition, and motion sensors to guide the robot, reflecting the kinds of creative solutions that emerge when learners design projects in response to authentic, everyday problems [10]. This initial plan, as well as a conversation with one of the camp facilitators, guided her initial design and prototyping process. She also responded to the daily reflection prompts provided in her digital design journal, documenting the successes, challenges, and next steps in developing her endangered species tracker.

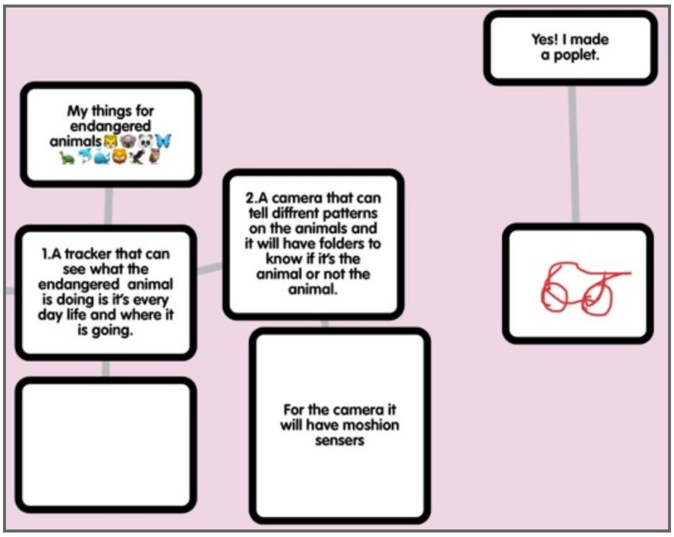

Figure 4. Emily's passion project brainstorming.

Emily encountered numerous challenges translating her design into reality, however her willingness to persevere through these challenges resulted in greater progress towards a working prototype than Anisha and Derick.

After learning that the maker camp was unable to acquire a GPS tracker within the required timeframe, she moved on to another element of her design without hesitation. Another roadblock emerged with the small tiger she had hoped to 3D print to represent the endangered species her project was designed for when each attempt failed due to issues with the stability of the 3D model. Instead of becoming discouraged, she and one of the camp facilitators kept track of the failures, noting which print had made the most progress. The camera element of her project also posed a challenge, both to her and camp facilitators. Given a lack of standalone camera components in the lab, this feature required that a smartphone be connected to her micro:bit via Bluetooth wireless technology and then coded to take a photograph at certain intervals. However, the connection between the smartphone micro:bit app and the physical micro:bit board was tenuous, and after a full afternoon of troubleshooting with one of the camp facilitators, Emily was willing to abandon this aspect of her project as well.

Figure 5. Camp facilitator helping troubleshoot Emily's micro:bit.

To finalize her project, Emily had to assemble k8, a micro:bit-compatible robot [32]. Although she tried to complete this task independently, she had trouble locating the assembly instructions as well as physically fitting the pieces together. One of the facilitators was able to assist with the assembly process, modelling each step but ultimately encouraging Emily to complete the assembly. At one point, Emily mentions, "I don't like assembling k8, k8 is hard to put together." However, this did not seem to deter her from completing the build and successfully coding the robot's movement. Although Emily was only minimally successful in creating a prototype of her endangered species tracker, she was able to continually make progress towards the end result, with or without the facilitators' assistance. The specificity of her original design, the planning and iteration that occurred through her daily reflections, and her ability to persevere through seemingly insurmountable challenges may have supported her process, acting as a framework to support ongoing progress towards a working prototype [5, 11, 25].

Amalya's texting-and-driving deterrent

Amalya (age 13) was inspired by the social justice theme of the camp, saying, "for my passion project, I decided to help change the world." She chose to expand upon a school art assignment which illustrated the degree to which people were dependent on their phones. Explaining further, she wrote, "I found out that there are more people dying because of texting and driving than drinking and driving. And, for me, that was so crazy."

Amalya spent more time in the planning phase of her design than most other participants, using not only the mind mapping application provided, but also her digital design journal to make detailed notes, and a digital painting application to create a rough sketch of her design:

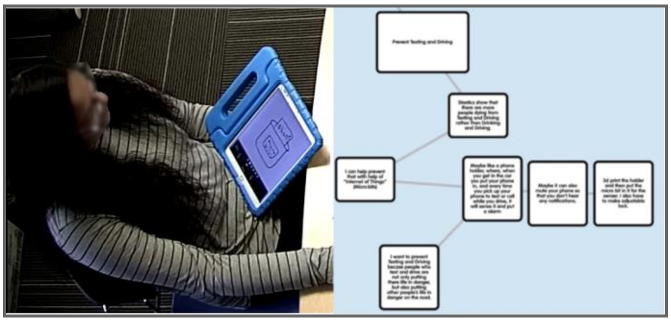

Figure 6. Amalya's passion project brainstorming.

Her thorough, extended engagement in the design process enabled Amalya to exercise her creativity [25], as well as determine her priorities regarding the final product [10]. She decided to make a 3D-printed phone holder that utilized the micro:bit's onboard sensors to detect when a phone was removed from the cradle and activate an alarm that would remind the user not to look at their phone while driving. While Amalya's initial design also featured an adjustable lock to physically prevent a user from removing their phone while the car's engine was running, as well as the ability to mute incoming notifications to prevent any temptation of a person attending to their phone while driving, she deemed these elements to be too sophisticated for her first prototype.

While working on her 3D model, Amalya sought input on her design from camp facilitators and similarly-aged peers. She wanted to ensure that her measurements were correct, and that her model would hold an average-sized smartphone (as well as the micro:bit and battery pack) so as to be accessible to as many people as possible. She was comfortable with the process of learning to use new technologies as needed for her design, but often asked for feedback and validation on her project's specifications and usability. Given her growing comfort with tools that had not been explicitly taught during the camp's exploration sessions, Amalya also offered assistance to those in her immediate vicinity and was asked to assist other campers when facilitators were occupied. Echoing Marsh and colleagues' [21, 22] observations of makerspaces as sites of enhanced agency, this generated additional self-confidence in her abilities, which was evident when she realized that she had made a mistake in her project's dimensions and opted to start over.

After achieving success throughout various stages of her design process, such as finalizing her 3D model and achieving a working prototype, Amalya was excited to share her results with others. She reached out to camp facilitators and campers she had become friendly with to show them what she had achieved. Her pride was also evident upon the camp's completion, when she indicated that she would be interested in working with automotive engineers to integrate a similar design into cars currently on the road. Over the course of the week, Amalya's discernible passion for this subject [7, 13] in combination with her robust approach to design [5, 11] and ongoing metacognitive engagement through reflective journal entries [24, 27] created a context in which she was able to conceptualize, iterate, and ultimately produce a functioning prototype of her texting-and-driving deterrent system.

5.2. How Does Understanding of IoT Develop in a Constructionist Learning Environment?

While we did not expect participants to become IoT experts over the course of a five-day constructionist learning microcycle, our data suggest that there may be value in providing immersive, hands-on exposure to such advanced technological concepts.

On the first day of camp, the pre-study questionnaire asked participants whether they were familiar with IoT or smart homes and devices. Only three (18%) answered in the affirmative, while the remaining fourteen were either unsure (59%) or decidedly unfamiliar (23%). However, two of the three participants who indicated that they had heard of IoT provided vague ("the internet is connected to every device") or incorrect ("Google") definitions, while an additional eleven campers (65%) further articulated that they did not know what IoT meant. Despite participants' lack of familiarity, opinions were mixed regarding their ability to use IoT to affect positive change in their lives or the lives of others: six (35%) believed that they could, four (24%) said maybe, and seven (41%) did not think so. Given that the majority (n=13, 76%) of our participants used technology at home "often" or "every day" and for a variety of recreational and educational purposes (including gaming, coding, and art), it is possible that they felt their comfort and proficiency with technology in general would translate to even unfamiliar technologies.

As many participants were still working on their passion projects up to the last moment of camp, only 10 (59%) post-study interviews were able to be conducted. By this point, participants had developed a more comprehensive understanding of IoT, describing features such as the interconnectivity of devices to one another and to the Internet (n=5), the use of a central device, typically a smartphone, to control connected devices (n=6), the role of artificial intelligence in IoT (n=3), as well as its ability to make life more convenient (n=2). Only one of the ten participants interviewed was unable to provide an accurate definition. Furthermore, participants identified numerous applications of IoT to improve their life or the lives of others, including driverless cars, reduced casualties of war due to unmanned planes and submarines, making homes more accessible for individuals with disabilities, increased home security and monitoring, and the automation of lights and appliances, resulting in money saved for consumers. They had also begun to form opinions on the use of IoT, describing it as cool (n=3) or useful (n=7), while emphasizing the need to protect data from hackers (n=6) with added layers of security, such as encryption or firewalls (n=2). While the short timeframe and unique context of this study prevent any generalization of its results, the potential for passion-based learning [13] and makerspaces [15–17] to facilitate deeper learning, even with sophisticated concepts such as IoT, has inspired a shift to accommodate these elements in formal education [13, 14].

6. Discussion & Conclusion

This study explored the impact of a five-day learning microcycle, in the form of a constructionist March break camp, on participants' natural, informal design processes and their understanding of IoT. Our findings suggest that, while guided inquiry can be an effective tool to drive students' passion-based maker projects and explore new concepts (such as IoT), the amount of guidance needed to support design decisions can vary widely, even within a small group. While many of our participants flourished with the ability to select and design their own projects with minimal constraints, others had difficulty progressing without a more well-defined plan. For these youth, a structured inquiry approach, featuring more explicit procedures and learning goals, may have alleviated their frustrations, promoted resiliency, and more effectively scaffolded their designs [19]. Furthermore, encouraging participants to design solutions for a problem they were personally invested in helped bolster their motivation in most cases, but the extent to which passion-based learning had a protective effect on their perseverance differed for each participant. Educators wishing to adopt an inquiry-based constructionist model in their own contexts will need to consider many factors, including time available for initial learning, exploration, and design, students' familiarity with the tools and technologies on hand, and the degree of structure required based on students' individual needs [21].

Several other factors were identified as affecting participants' informal design processes, including the comprehensiveness of their initial plans, the role of camp facilitators and peers in providing motivation, validation, or focused support as a "more knowledgeable other" [33], and the impact of perseverance and failure-positivity.

Participants who were more detailed in their planning and set explicit goals for themselves in their reflective journals at the end of each day experienced fewer challenges in the process of making and were better prepared to navigate the issues that did arise than those who did the bare minimum. In addition, providing a context in which participants felt empowered to take risks was paramount to the design process [24]. Through an emphasis on participants' big ideas as well as the power of mistakes for iteration and refinement of their designs, many demonstrated a willingness to engage with new concepts and technologies in the interest of developing creative, unique and personally-relevant passion projects. However, a notable limitation of our research design was the scope of the project to be completed in a relatively narrow timeframe. Participants were tasked with learning about a new concept (IoT), exploring unfamiliar technologies, and engaging in the design process to model, construct, code, test, and iterate upon a project of their own design within a span of five days. This timing precluded researchers from providing participants with a thorough introduction to the design process, and only surface-level engagement with some of its key components, such as ideation, observation of human need surrounding their solution, and metacognitive engagement [11, 24, 27]. While iteration, failure positivity, and growth mindset were emphasized throughout the week, we may have insufficiently communicated the importance of setting a solid foundation for design work in the form of a plan, which resulted in several participants doing only as much as they felt was required by the facilitators. Yet, despite the challenges faced by some of our participants, our results support Doppelt's [10] assertion that students' engagement in the process of conceptualizing, creating, and sharing solutions in response to authentic problems is more important than the specific design process model used to do so.

Our research also suggests that engagement with low-floor IoT technologies in a constructionist environment, such as a community makerspace or a maker-oriented classroom, may facilitate a deeper conceptual understanding of IoT and its real-world applications. Contrary to Carroll and colleagues' [24] observations that students found it difficult to acquire curricular content knowledge in parallel with their design work, participants in our context demonstrated an improvement in their understanding of IoT by the end of the study. Regardless of their success in producing a functional prototype, after working with their design for a short week, most of our participants were able to describe key features of IoT, including the interconnection of everyday devices, the need for management software to define interactions and set parameters, and the role that artificial intelligence plays in IoT. Participants were also able to offer suggestions for the use of IoT to benefit society, many of which were original ideas not covered in the group discussions or daily videos. While the scope of our March Break camp prevented an in-depth exploration of the more advanced connectivity, programming, and monitoring elements of IoT, these topics could easily be included in subsequent iterations with a longer timeframe and expanded in complexity as students get older.

These findings have compelling implications for educators of 21st century students. As IoT becomes a salient feature of society, future citizens must understand not only how it works, but also how to protect the personal data that sits at the core of these systems. Moreover, careers in IoT development are expected to increase as steadily as the number of connected devices [4], further elevating the value of IoT knowledge, as well as the design processes needed to effectively work with these technologies. As both the maker movement [19] and the integration of technologies for communication, coding, digital production, and more [34] continue to grow within formal education, multipurpose electronics kits like the ones used within this study can be used to introduce the basic concepts and concerns associated with IoT to K-12 students, better preparing them to live and work in a highly-connected society. Engaging students in critical making activities [17], whether at school or during visits to a local makerspace, can be another effective way to integrate IoT and other technologies into learning. Through a blend of traditional crafting and digital tools [18, 22], and an emphasis on low-floor, high-ceiling technologies [9, 12], makerspaces can offer a natural bridge into the digital landscape for learners of all ages. Our study benefited from an unusual instructor-to-student ratio (approximately 1:6), however the implications of using the design process within an inquiry-based constructionist learning environment to explore complex technologies or promote interdisciplinary learning contained herein are worth exploring within formal educational contexts.

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