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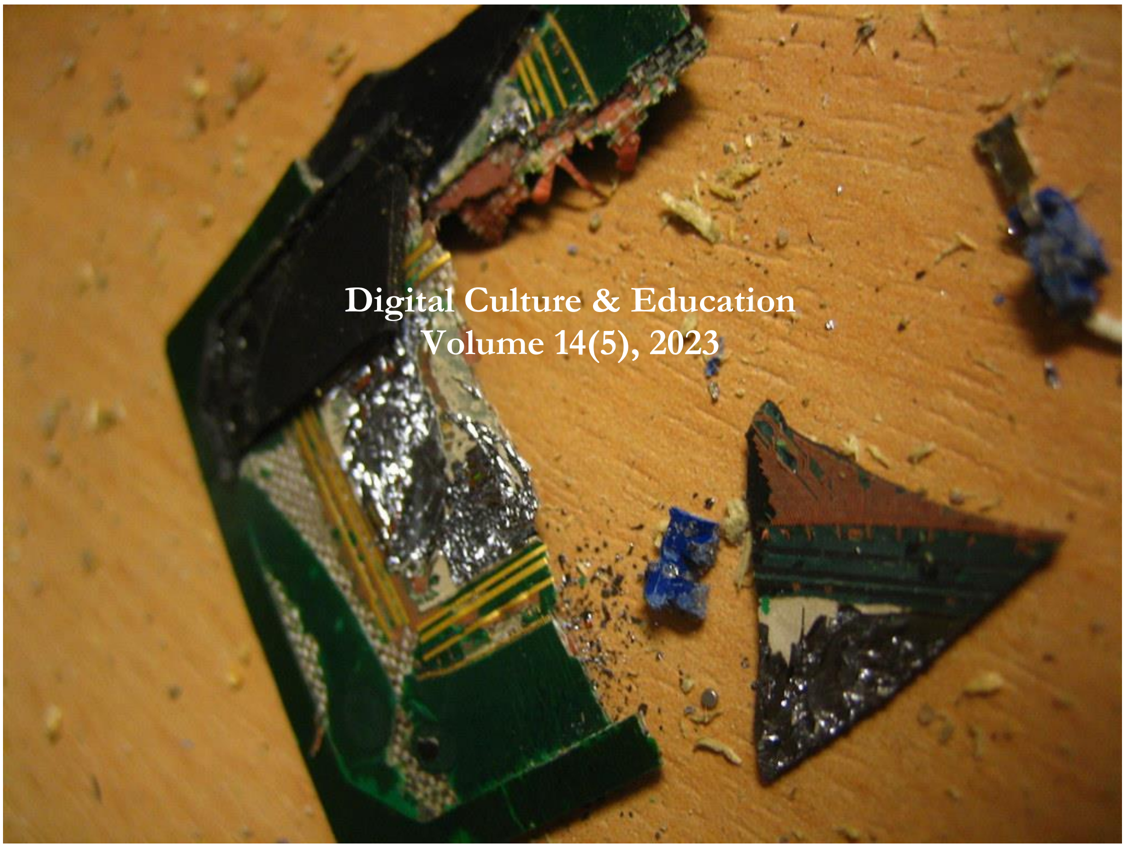

# Techno-vegetal Collaborations: Plants as Collaborators in the Design of a Computer Science Learning Environment

**Michael Lachney**
Michigan State University, East Lansing, United States

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# Techno-vegetal Collaborations: Plants as Collaborators in the Design of a Computer Science Learning Environment

Michael Lachney[1]

[1]Michigan State University, East Lansing, United States

**Abstract:** *Posthumanist educational methodologists, theorists, and researchers tend to reproduce zoocentrism by privileging animals over plants in their scholarship. This comes at a time when disciplines from across the academy are taking "plant turns" by attending to plants' abilities to sense and communicate, as well as their material relationships, representational significance, and lively entanglements with non-plants. This amounts to a rejection of traditional Western science and philosophy that treat plants as passive forms of life. To encourage this plant turn in posthumanist educational scholarship, I turn toward Anishinaabe-gikendaasowin, plant science, and continental philosophy to help recognize the agencies and behaviors of plants that challenge human exceptionalism. I engage with these knowledge systems through multispecies storytelling about the collaborative design of a library computer science learning environment. Multispecies stories from these collaborations not only show how plants contributed to computer science learning, but also how they affected and were affected by humans, nonhumans, and technologies in the library. These findings have implications for posthumanist educational research and computer science education.*

**Keywords**: *posthumanism; plant turn; computer science education; zoocentrism; Anishinaabe-gikendaasowin; plant science; continental philosophy*

## Introduction

Western knowledge production tends to reproduce *zoocentrism* by privileging a focus on animals while marginalizing vegetal or plant lives. Consider, for example, that in 2019 a "quick survey of the scientific literature of the last five years reveal[ed] that, on average, only one paper is published on plants for every two published on animals" (Gagliano, Ryan, Vieira eds., 2019, p. viii). This discrimination against plants partially stems from a view of vegetal life as passive. Despite plants being fundamental to all life on earth (from food to energy and air), zoocentrism treats plants as lesser than and subordinated to animals (including humans) in the hierarchies of Western philosophy and science, ultimately excluding them from moral consideration (Hall, 2011). This is problematic in the face of proliferating ecological crises that make it starkly obvious that humans are not and have never been outside of "nature."

Unfortunately, zoocentrism is also reproduced in posthumanist educational methodology, theory, and research. While it would be a mistake to say that plants are not part of the agentic assemblages and relationships that posthumanist educational researchers report on (e.g., Eglash et al., 2020; Pacini-Ketchabaw, Taylor, Blaise, 2016; Rotas, 2015), specific attention to vegetal lives is sparse compared to animals. For example, two anthologies on posthumanism and education that include multispecies research provide index entries for "animals" or topics about animals (e.g., "animal emotions", "animal rights", "animal interiority", etc.), but neither includes entries for plants, vegetation, or vegetal life (Snaza & Weaver eds., 2015; Taylor & Hughes eds., 2016). This absence comes at a time when fields like critical plant studies (e.g., Woodward & Lemmer, 2019) are growing. This field is part of a larger *plant turn* taking place across academic disciplines; a turn that seeks to attend to plants' behaviors of sensing and communication, as well as their material relationships, representational significance, and entanglements with non-plants (e.g., Hartigan Jr., 2017; Miller, 2019).

Plant turns across academia engage with plant science, Indigenous and Diasporic knowledge systems, philosophy, art, literary criticism, and other sites of knowledge production that are challenging long held views of plants as passive life forms, unidirectionally determined by their environmental contexts (Vieira, Gagliano, & Ryan eds., 2015; Gagliano, Ryan, Vieira eds., 2019). Consider, for example, how research into plant behavior, communication, and non-conscious and non-cognitive forms of intelligence show dynamic organisms who interpret their environments, communicate information, collaborate with other organisms, engage in communities, and learn from experiences (Chamovitz, 2012; Trewavas, 2014; Karban, 2015). Philosophers have also turned their attention to plants, framing them as active agents and co-producers of meaning that can help to deconstruct metaphysics (Marder, 2013) and orient communities toward commitments to co-existence and interdependence (Irigaray, 2019). In addition, Indigenous scholars such as Robin Wall Kimmerer (2013) and Wendy Makoons Geniusz (2009) are sharing stories about botanical Anishinaabeg knowledge (i.e., *Anishinaabe-gikendaasowin*) where plants are collaborators and teachers, participating in *webs of reciprocity* that include both biotic and abiotic entities.

How might posthumanist educational methodologists, theorists, and researchers be accountable to plant agencies and relationships in their scholarship? This paper will answer this question by bringing together literature on plant agencies and relationships with storytelling methods from multispecies studies. The goal is not to replace the primacy of animals with a primacy of plants but instead focus "on the multitudes of lively agents that bring one another into being through entangled relations" (van Dooren, Kirksey, & Münster, 2016, p. 3). Through multispecies storytelling (see Bencke & Bruhn eds., 2022; Haraway, 2016), I show how communities of educational researchers, librarians, urban farmers, and cosmetologists collaborated with communities of plants—pennyroyal mint and spike lavender—and fish—male guppies—that grew with the small-scale socio-technical environment of a library aquaponics system. These communities collaborated to make natural cosmetic products and programming activities for a computer science education summer library program.

## Situating Vegetal Lives in Posthumanist Educational Scholarship

### *Plant Agencies & Relationships*

Animals have long been treated as "passive objects of human agency" (Mullin, 2002, p. 390), but the Western perception of passivity for plants has been greater due, in part, to illusions of their immobility and insensitivity (Gagliano, 2015). Gagliano (2015) uses the term "plant blindness" to describe patterns in Western science and philosophy that disregard the agencies of vegetal beings and overlook their central roles in co-shaping earth's ecologies. Western theories and experiments that affirm plant sensitivity have been around since the seventeenth century and due to standards about including photosynthesis in school textbooks it is common knowledge for many children in the U.S. that plants adjust themselves in relationship to light. Still plants have been assigned lesser value than animals from Aristotle to present day scientific communities (Gagliano, 2015).

Challenging the view of plants as passives means understanding that they have always been in relationships with others. This includes their entanglements in histories of imperialism and colonialism (Brockway, 2002). For example, Brockway's (2002) classic study on British royal botanical gardens shows their material and epistemic roles in the colonial expansion of the British Empire in the nineteenth and twentieth centuries. But Indigenous and Diasporic communities have their own knowledge systems that have helped them to work outside of, negotiate, and/or resist extractive and exploitative human-vegetal relationships (Augusto, 2017; Carney, 2002; Descola, 2013). For example, Augusto (2017) explains that enslaved Africans who were forced to the Americas brought with them Indigenous botanical and agricultural knowledge. Some of this knowledge was colonized by settlers to further white supremacist land exploitation and racial capitalism, but Augusto (2017) explains how Black individuals', families', and communities' botanical knowledge and relationships were sites of technological innovation and creativity that supported survival while in bondage and self-determination when liberated from it. Indigenous communities in the Americas also have their own epistemologies and ontologies for human-plant relationships, many of which do not view plants as passive or completely distinct from humans (Kimmerer, 2013; Miller, 2019).

In this paper I turn toward botanical Anishinaabe-gikendaasowin as one example that challenges zoocentrism by being accountable to plant agencies and relationships in research and practice (Kimmerer, 2013; Geniusz, 2015). The use of the Anishinaabemowin term *Anishinaabe-gikendaasowin* is from Geniusz (2009) who explains that it refers not to knowledge generally, but to the specific knowledge of Anishinaabe people. The Anishinaabe people or Anishinaabeg are made up of a diversity of culturally and linguistically related Indigenous communities from around the Great Lakes region of North America and include "the Three Fires Confederacy of the Ojibwe (Chippewa), Odawa (Ottawa), and Bodwewaadomi (Potawatomi), as well as other Anishinaabemowin speaking tribes" (Eglash et al. 2020, p. 1572). Like Western scientific knowledge production, Anishinaabe-gikendaasowin is based on close and systematic observations of the natural world and replicable experimentation but, unlike Western science, it is produced over much longer periods of time with the results often being iteratively transmitted orally across generations (Kimmerer, 2013; Doerfler, Sinclair, & Stark, eds., 2013; Geniusz, 2015). The colonization of Indigenous knowledge was part of the violence of colonizing land and peoples: "not only did colonizers benefit from native botanical knowledge, they also were able to use this knowledge to fuel their imperialist efforts" (Geniusz, 2009, p. 3). Therefore, part of decolonization projects is decolonizing knowledges that have been assimilated, revitalizing them in service of those projects.

Revitalization has been part of the mission of Citizen Potawatomi Nation member and botanist Kimmerer (2003), who explains that in the Potawatomi tradition every being "is endowed with certain gifts, its own intelligence, its own spirit, and its own story" (p. 100). Plants are no exception, as they can be teachers who have their own wills and agencies to reveal insights about themselves and the world. For example, Kimmerer (2003) and Grover (2017) discuss how the comings and goings of plants can reveal insights about the seasons, as well as the interconnected needs of ecologies. This can be part of knowledge production when humans participate in a "web of reciprocity" where everyone involved is interconnected and thus shares responsibility for themselves and others (Kimmerer, 2003, p. 110).

While recognizing the need to attend to differences across epistemic systems, Kimmerer (2003) notes that traditional Indigenous knowledge and Western science are intellectual twins. This is an exciting observation since stories about interconnectedness are also included in research on plant behavior and intelligence (Baluška & Ninkovic eds., 2010; Trewavas, 2014). Many in Western science have assumed that plants do not exhibit behavior because they do not move, but as Trewavas (2014) points out, changes in the growth of plants are equivalent to movement in animal behaviors. Cooperative behaviors between different plant species growing adjacent to each other have been observed when they emit volatiles to communicate about potential threats (Trewavas, 2014, p. 186). There is also well documented evidence of plant-animal communication that results in collaborations where animals may receive nutrients when aiding in plant reproduction (Karban, 2015, p. 109).

One claim about plant behavior is that it reveals non-cognitive forms of intelligence. This requires a more-than-human view of intelligence that definitionally breaks from a reliance on brains and nervous systems or "brain chauvinism" (Trewavas, 2014, p. 201). This definition of intelligence is based on individual- or species-environment interactions that result in adaptation and problem-solving. Therefore, general biological intelligence is the capacity for responding to and solving problems within encountered environments. And, since brains are only one means for problem-solving in the biological world, intelligence should be judged within the material and structural constraints of the organisms in question (Trewavas, 2014). But for plants to have this capacity requires that they can learn from experience. Indeed, plants learn and store information from past experiences (i.e., "memories") with environmental stimuli, including but not limited to light and chemicals (Karban, 2015). Trewavas (2014) explains, "Learning in plants, as in other non-neural organisms, involves perception of a stimulus, activation of a transduction pathway, and a subsequent change in behaviour; the flow of information in the cells has been altered" (p. 170). But even when the stimulus stops the pathway can remain and this is what constitutes plant-memory.

The agentic view of plants that is posited by research on plant behavior and intelligence has rattled traditional Western views. Phenomenology and continental philosophy help Marder to (2013) further this project by centering the ontology of plants in a deconstruction of metaphysics. A methodology of *plant-thinking* is formulated by Marder (2013) to support material and philosophical encounters with vegetal life without having them be subsumed by forms of conceptualism that reduces and restricts the possibilities of plants by fitting them into a priori categories. Plant-thinking refers to the "non-cognitive, non-ideational, and non-imagistic mode of thinking *proper* to plants", human thinking about plants, how human thinking is dehumanized and rendered plant-like in encounters with plants, and the symbolic relationship between this plant-like thinking and plants themselves (Marder, 2013, p. 10).

One key insight that Marder (2013) takes from plant-thinking is about time: "the meaning of vegetal being is time" (p. 95). Marder identifies three variations of plant-time: the multiple temporalities of seasonal changes, the infinite but material constraints and interruptions of growth, and the cyclical patterns of vegetal iteration, repetition, and reproduction. These plant-times appear distinct from those of humans', so much so that their very behaviors overtime can go unnoticed and were not fully elucidated until the use of time-lapse photography (Trewavas, 2014, p. 13). But encounters with plants' temporal modes shape our own existences (Wood, 2020), from the burning of fossil fuels derived from ancient plant life to the wilting kale that sits in our refrigerators, or the variations of seasonal shade that trees might provide to a house. From these examples, it becomes clear that the surface and appearance of plants is defined by inclusive sharing and participating with others, "free of any expectations of returns from the other" (Marder, 2013, p. 52). While this sharing is essential to all animal life, it also leads to extraction and exploitation, which Marder (2013) argues is often motivated by Western metaphysics and, hence, there is a need for a program to deconstruct it.

### *Posthumanism & Multispecies Studies*

In posthumanist theory and research that include animals and/or plants, humans often become decentered by crisscrossing disciplinary boundaries between the life sciences, humanities, and social sciences (e.g., Haraway, 2008; Weaver, 2010). Doing so helps scholars acknowledge how phenomena and traits that have traditionally been reserved for humans in Western knowledge production can appear across species, albeit in different and even incommensurable ways (Morris, 2015). Consider how in some sub-disciplines of plant science (e.g., plant neurobiology) terms like behavior, intelligence, language, learning, memory, and consciousness are being used to explain vegetal lives and their relationships to other beings and environments (Mancuso, 2017; Gagliano, Ryan, Vieira eds., 2019). Of course, applying these terms to plants is metaphoric and reflects the difficulties of escaping human exceptionalism because we "remain confined by the associative powers of linguistics, limiting our views of non-signifying or non-semiotic intelligences" (Brits & Gibson eds., 2018, p. 20).

Therefore, the goal is not to subsume plant intelligence or culture into those of humans, but instead acknowledge resemblances and continuities across species lines while allowing for the unique and relational contexts and criteria of each to be understood on their own spatial and temporal terms (Baker, 2019). For example, there may not be a strong continuity between plants and humans in terms of how they engage with the past, present, and future (Wood, 2020). But, as noted above, it may be that plants, in their many species (over 390,000 to date), have their own ways of remembering and anticipating that are distinct from those of humans and nonhuman animals, not to mention varied among themselves (Trewavas, 2014). These types of continuity-discontinuity tensions are what posthumanism grapples with when problematizing human exceptionalism.

To problematize human exceptionalism, posthumanism recognizes the nonhuman agencies by attending to their relational interdependence and entanglements at multiple spatial and temporal scales. Posthumanist scholars often turn to multispecies studies to understand these forms of interdependence and entanglement in their historical trajectories and immediate contexts. Multispecies studies do not give primacy to any one form of agency, biotic or abiotic (van Dooren, Kirksey, & Münster, 2016). Just because plants have been neglected does not mean that inverting the hierarchy will correct past wrongs or do justice to them. Any species, including our own, can only be understood through how it is historically and currently co-constituted with other species, all acting on, in, with, through, and as their own environmental contexts (Wood 2020).

### *Biotic and Abiotic Agencies in Posthumanist Educational Research*

Posthumanist educational scholars have moved toward post-anthropocentric methodology, theory, and research by paying the most attention to material and nonhuman animal agencies and relationships (Ceder, 2019). Technology and material agencies have been particularly important for posthumanist research on human-nonhuman collaborative learning (e.g., Keune, Yankova, & Peppler, 2021; Eglash et al., 2020). Much of this work has challenged the view of technologies as mediators of worldly experiences by positing that they are, instead, actively constitutive of them. To clarify, consider how science and technology studies scholar Pickering (1995) uses the metaphor of "tuning"—think about tuning a radio to capture a certain frequency—to describe how scientists collaborate with experimental instruments to capture material agency of the world to try and solve problems posed by their epistemic communities (p. 20). Tuning is not about technologies as mediators between humans and the world, it is a metaphor that is meant to signal posthuman space of human-nonhuman negotiation and collaborations.

Challenging the view of technological mediation in learning, Keune, Yankova, & Peppler (2021) explain how in human-nonhuman collaborative relationships the materials and technologies, not just humans, are agentic in creative design and problem-solving. They explore how crafting materials, crafters, and technologies take on agentic roles in the collaborative production of textiles. This supports a conclusion of posthumanist educational methodologists that learning and learning environment designs can be based on the creative emergence of many different biotic and abiotic agentic relationships. In other words, learning and learning environments are not things to be pre-determined and then designed for and by humans (Chappell, 2018). When human-technology collaborations are studied as learning, design, and problem-solving then emergent and playful relationships of humans and nonhumans coming-together to shape each other, as well as shape and be shaped by their environments, are presented (Keune & Peppler, 2020; Chappell, 2021). This paper contributes to Keune, Yankova, & Peppler's (2021) research on posthuman collaborations by introducing the concept of *techno-vegetal collaborations*: human-nonhuman collaborations that make space for vegetal life and agency.

Another example of posthumanist educational scholarship that includes a focus on nonhuman agencies is found in research that engages with multispecies studies and critical animal studies (e.g., Taylor, 2013; Morris, 2015; Pacini-Ketchabaw, Taylor, Blaise, 2016). The focus on nonhuman animals is unsurprising considering that they have long been community members in schools, classrooms, and educational spaces generally. For example, Ceder (2019) uses the example of "literacy dogs"—dogs that children read age-appropriate books to, in a safe and non-judgmental environment—to decenter learning as individualistically directed toward a priori subjects (e.g., children or dogs). Instead, Ceder (2019) introduces a posthumanist framework of educational relationality where dog-human agencies are entangled and constituted in mutual encounters and collaborations.

Since these types of multispecies encounters and collaborations invoke historical relationalities and contribute to changing the contexts in which they are situated, posthumanist educational researchers often attend to the ethics of these entanglements, necessitating accountability to the activities that emerge and the other entities involved. Consider, for instance, how Taylor and Pacini-Ketchabaw's (2015) early childhood research on multispecies pedagogies highlights how opportunities for ethical engagements with the topics of ecological vulnerability and interdependence grew out of ant-child and worm-child encounters. While they found the agencies of ants and worms recognizable in their research, more challenging was resisting anthropocentric moral attitudes toward children.

If decentering humans in research on animal-human educational encounters is difficult, the hegemony of zoocentrism might suggest it is even more so for plant-human encounters. When plants do appear in posthumanist educational scholarship it is often in passing or written about without attention to the particularities of vegetal lives. For example, in an important essay on "ecologies of praxis", Rotas (2015) uses the examples of school gardens and classroom lima bean experiments to critique mainstream forms of environmental education. While Rotas returns to the practices and human-nonhuman entanglements of gardening to clarify posthumanist theories of agency, the particularities of vegetal lives are not mentioned and the majority of the chapter goes on to attend to the agencies of worms.

Zoocenterism does appear often in posthumanist educational scholarship, but it should be noted there are a small number of feminists working at the intersections of education, posthumanism, and new materialism who do include literature from critical plant studies in their work (Ringrose, Warfield, & Zarabadi eds., 2019; Mcphie & Clarke, 2019). For instance, Mcphie & Clarke (2019) draw on philosophical explorations of "plant-thinking" (Marder, 2013) to orient readers toward a process-oriented environmental education of becoming-with that challenges both anthropocentrism and views of vegetal lives as passive. I contribute to this work by asking the question: How might posthumanist educational methodologists, theorists, and researchers be accountable to plant agencies and relationships in their scholarship?

## Methodology

To answer this question, I turn to human-nonhuman collaborations that were formed in and around an aquaponics system—a techno-social system for growing fish and plants together—at a midwestern U.S. urban public library between January 2019 - September 2019. The system had been set-up to grow plants for making natural cosmetic products as part of a summer computer science program at the library. This program was inspired by the fact that the library already had programs on Black natural hair care, computer science, and urban gardening. During late 2018, three librarians had proposed working with me to find ways to bridge these programs for the purposes of creating a new summer program that would appeal to children with one or more of these interests. I worked closely with the librarians to connect with urban farmers and cosmetologists who lived in the area and were willing to collaborate with the librarians, my research team, plants, animals, and technologies to co-design the activities for this summer program.

To understand, analyze, and write about this collaborative posthuman co-design process, I turn to multispecies storytelling as a methodology for expressing encounters between humans, plants, nonhuman animals, and technologies (Bencke & Bruhn, 2022; Haraway, 2016). Haraway (2016) explains that storytelling is troublesome and involves posthuman knots of living and dying; the goal is not about pure representation of posthuman relationships or reconciliations of difference, but an expression of these relationships that is about "partial recuperation and getting on together" (p. 10). An affordance of multispecies storytelling is that it opens posthuman space for not only biotic but abiotic relationships (e.g., not just the plants but the media they are grown in). But the task remains of how to narrate and express these encounters so that nonhumans are not totally ventriloquized or subsumed into human semiotic logics, while also recognizing the need to be accountable to the inevitability of these logics and narratives when working in anthropocentric institutions and legacies of knowledge production.

To compose multispecies stories, I learn from Marder's (2013) methodology of plant-thinking that includes not only a focus on the non-cognitive aspects of vegetal thinking and how humans think about plants, but also how these human and plant modes of thinking co-shape each other when put into relationships. To understand these relationships, I also learn from the storytelling work of cultural botanist Ryan (2020) on *phytography* or treating plants as active storytelling figures. There are two composition principals to phytography: 1) "*writing-with*" - posthuman writing where humans and plants are in dialogue; 2) "*writing-back*" – plants using their own sensorial and material methods to write their own lives into the world, beyond human relationships (Ryan, 2020, p. 99). McEwan (2022) explains that plants have corporeal rhetoric that leave botanical traces in the world (writing-back) and have the potential to affect others. Multispecies storytelling can attend to these affective traces with posthuman methods of writing-with plants. They are part of plants' own pedagogies. Writing-with requires understanding how botanical traces are left from vegetal intelligence and behaviors of plants (Maher, 2017).

Three data sets were collected around the co-design of the computer science learning environment and co-maintenance of the aquaponics system at the library. These data were studied for traces of posthuman relationships and techno-vegetal collaborations, with special attention to botanical traces or how the plants wrote themselves into the location of data collection and the data themselves. This helped me to work toward a method of writing-with. First, I used data from urban farmers, educators, and cosmetologists who helped to decide what plants to grow in the aquaponics system. Here I examine the ways that plants left traces on these human collaborators by studying their preferences for certain plants and the reasons behind their preferences. Second, I used pictures taken of the aquaponics system and documentation of multispecies interactions from notes and emails during the design of the computer science learning environment that grew out of the system's maintenance. Here I look for traces of how the multispecies relationships were negotiated and how the negotiations affected choices made in the design and implementation of the computer science learning environment at the library.

Third, I analyzed five one-on-one interviews (ranging between approximately 13-25 minutes) and three focus group interviews (approximately 30 minutes each) from the librarians who were responsible for monitoring and upkeeping the aquaponics system where the plants and fish grew. I specifically write-with the plants by looking for botanical traces that the librarians said affected them, the library space, and the library patrons. These data were thematically analyzed (Braun & Clarke, 2022). First, I became familiar with the data set through iterative processes of reading and notetaking. Second, I used concept coding to assign a "word or short phrase that symbolically represents a suggested meaning broader than a single item or action" (Saldaña, 2016, p. 292). Third, I generated themes from the codes before, fourth, reviewing and revising the themes. I then, fifth, defined the themes and, sixth, wrote prose about the themes. For this paper, I weaved one theme that emerged from this analysis, *intergenerational learning*, together with two sub-themes (i.e., *multispecies interactions* and *plant-time*) that were identified from reading this theme through the literature introduced above.

## Techno-Vegetal Collaborations

### *Choosing Seeds & Volatile Memories*

The three librarians who I had been working with agreed that a small-scale aquaponics system would be set up in their youth center. We hoped it would be used to bridge computer science education, Black natural hair care, and urban gardening, all existing areas of programming at the library. Aquaponics are techno-social systems where plants, fish, microbes, humans, technologies, and others collaborate. The fish and plants grow "symbiotically" as the "waste product from the fish provides the food for the plants, and the plants in turn filter the water that goes back to the fish" (Bernstein, 2011, p. 2). Aquaponics systems can be designed at many scales. For the library we chose a ten-gallon tank and a plant bed that could be secured on top, with a pump that moved water up into the bed before draining back down into the tank (Figure 1). The goal was for plants to grow that we could harvest for the program that upcoming summer. They were to be included in a lesson where children learned about algorithms through following and making natural cosmetic recipes and putting them into conversation with Arduino code. Five male guppies were transported to the tank so that their waste could act as fertilizer. But what seeds were to be germinated?

*Figure 1. The aquaponics set up at the library. (Source: Author)*

During January 2019, a one-day workshop was held that brought together urban farmers, cosmetologists, and educators (i.e., librarians and a teacher) to help test and design possible computing activities for the summer program. In addition, I introduced the aquaponics system and asked them to write down recommendations for what seeds to plant for growing individuals that could be used in the processes of making the natural cosmetic products. Sixteen people participated in the workshop and eight of them provided suggestions about what plants to grow: three urban farmers, three cosmetologists, and two educators.

The most popular suggestions across all three groups were mint (five suggestions) and lavender (five suggestions). The next most popular suggestion was basil (three suggestions), which was suggested by the three urban farmers. One urban farmer also suggested dill and another suggested coriander. One of the educators suggested chives. All three cosmetologists mentioned mint and two were explicit about the smell. For example, "Bitter menthol smell[;] good for opening up". The only urban farmer who mentioned mint included it with basil and coriander because, "All three can be used alone or in recipes for a variety of medicinal, culinary, or hygienic reasons". Lavender was also mentioned for its smell. But one of the urban farmers who only suggested basil warned against lavender because, as she explained, it "can take 60+ days to get a flower"; a trace of intimate plant-human relational knowledge.

Seeds for mentha pulegium or pennyroyal mint and lavandula latifolia or spike lavender were planted and germinated (Figure 2). The dormant seeds came from small seed packages, where they waited for the right conditions of water and light. The seeds were sprinkled among lava rock media because they were pH neutral and porous for helping water drain through. We also included some rockwool cubes. Above the plants was a grow light, shining down to help awaken the seeds and provide light to the plants in the library basement. Even though the plants grew for over sixty days, the lavender decided not to flower. Maybe a sign that I was not listening to them close enough to fully engage in their teachings and gifts.

In reading some of the workshop participants' comments about their suggestions, the germination of the seeds was shaped by traces of prior interactions with mint and lavender, largely based on experiential knowledge of their smells. Plants often use volatiles as part of their reproductive strategies, such as attracting and enrolling pollinators, and they are a key part of what Raguso and Kessler (2019) call their "ancient chemical language" (p. 28). These volatiles are what human smell. For generations, human-plant interactions based on the smell has resulted in the reproduction, cultivation, and uses of mint and lavender (e.g., Maia & Moore, 2011; Ellena, 2022). And today artificial and plant based lavender and mint products, from essential oils to soaps, are common in U.S. markets and probably beyond.

*Figure 2. The mint and lavender begin to grow. (Source: Author)*

But in the case of the workshop participants there were no human-plant interactions for them to have volatile experiences; the seeds that were to be planted were dormant, a unique behavior in and of itself that helps them to account for environmental variation in non-domesticated settings (Trewavas, 2014, p. 161). Instead, the workshop participants relied on their memories, traces of prior plant-human interactions. Moving beyond brain chauvinism, it can be argued that both neural and non-neural organisms have memories, which act as the foundation for learning and intelligence. In both cases pathways are created by experiencing external stimuli and memory is constituted when pathways remain and can be recalled in the absence of stimuli. For plants, non-neural transduction pathways may remain to result in the synchronous raising of leaves with the sun or "by remembering past attacks, individual plants learn to adjust their volatile responses to be better prepared for future battles" (Gagliano, 2019, p. 93).

For humans, neural pathways may remain after information is passed through synapses to create connections of varying strengths and the memory is stored in the hippocampus. The volatiles from plants interact with the olfactory bulb of human noses that have a close physical proximity to the regions of the brain that are linked to memory and emotion; indeed, researchers have found greater brain activity associated with smell than sight (Arshamian et al., 2013). I have often used lavender beauty products of various qualities, but one of my own memories with lavender(plant)-animal interactions was at a lavender farm in northern Michigan. I was not only impressed by the aroma of the plants but the 360 degrees of bees buzzing as they pollinated. For some of the workshop participants and myself, prior plant-animal interactions created memories about mint and/or lavender volatiles and/or products, which could then be drawn on during the co-design of the library program.

### *Webs of Reciprocity as Computer Science Education*

While setting up and maintaining the aquaponics system, I aimed to take seriously an ethical responsibility to be accountable to not only the librarians but the web of multispecies relationships that were constitutive of the system. Drawing on Anishinaabe-gikendaasowin, Kimmerer (2003) explains that humans have a responsibility of stewardship and respect for plants, and that this is wrapped up in *webs of reciprocity* where knowledge and resources are exchanged in cyclical acts of caring for one another across differences. If we were able to care for the fish and plants, would they help children learn about algorithms through making natural cosmetic products? And could reciprocal care between humans and nonhumans be computer science education? While thinking through these questions, I took inspiration from LaPensée (2017) due to her expertise in technology and Anishinaabe-gikendaasowin. Learning from the way she positions plants in the alternate-reality game *Techno Medicine Wheel*, I sought to relate to plants not as objects to be acquired and used but instead as collaborators and teachers who have their own ways of being and knowing (LaPensée, 2017). If I were to listen to and care for them, would the mint and lavender contribute to the design of the computer science learning environment at the library?

Once the aquaponics system had been set up for a short period of time the librarians who were responsible for informing patrons about the project, upkeeping the system in between research visits to clean it every 1-2 weeks, and feeding the fish, quickly revealed a problem. It turned out that the library was closed on Sunday and, therefore, no one would be there to feed the fish, resulting in their hunger and less fertilization for the plants. Indeed, it was recommended that the "fancy" male guppies or poecilia reticulata (Figure 3) be fed twice a day, twelve hours apart, to stay healthy. The librarians came up with a plan to come in early on Monday to feed the fish right away, but I worried that this would create more strain on the librarians who were already doing extra work with the system. Meanwhile the fish and plants would still miss a day of nourishment. The librarians did their best as I worked with my research team to try and come up with a solution.

*Figure 3. A pet store tank of fancy male guppies. Five guppies from the pet store were eventually transported safely to the library aquaponics system. (Source: Author)*

In collaboration with a graduate student and a youth library patron, I sought to find a way to automate the fish feeding process on Sunday. We began by coming up with a prototype. We programmed an Arduino microcontroller to manipulate a servo motor, while experimenting with several fish food delivery systems. First, we used materials for the delivery system that were easily accessible within the library, thinking that librarians might need to replace and replicate parts of the design at later dates. We started out by cutting holes in a simple plastic cup, putting tape over the opening, and using adhesive to secure it to the motor, which was programmed to deliver the food at specific time intervals (Figure 4). However, the aquaponics system pushed back. The everyday materials were not suited for the dimensions of the tank and the prototype was too imprecise for delivering food. Therefore, the next prototype involved a more solid and level plastic container with a lid that could pop open and be tightly closed (Figure 5). We cut an opening in the new plastic container for food to be delivered into the tank. We also cut a hole into the top of the tank's lid so it could be open and closed even with the fish feeder attached. Indeed, the librarians reported that it was common for items to be dropped or to fall into the tank when the lid was open.

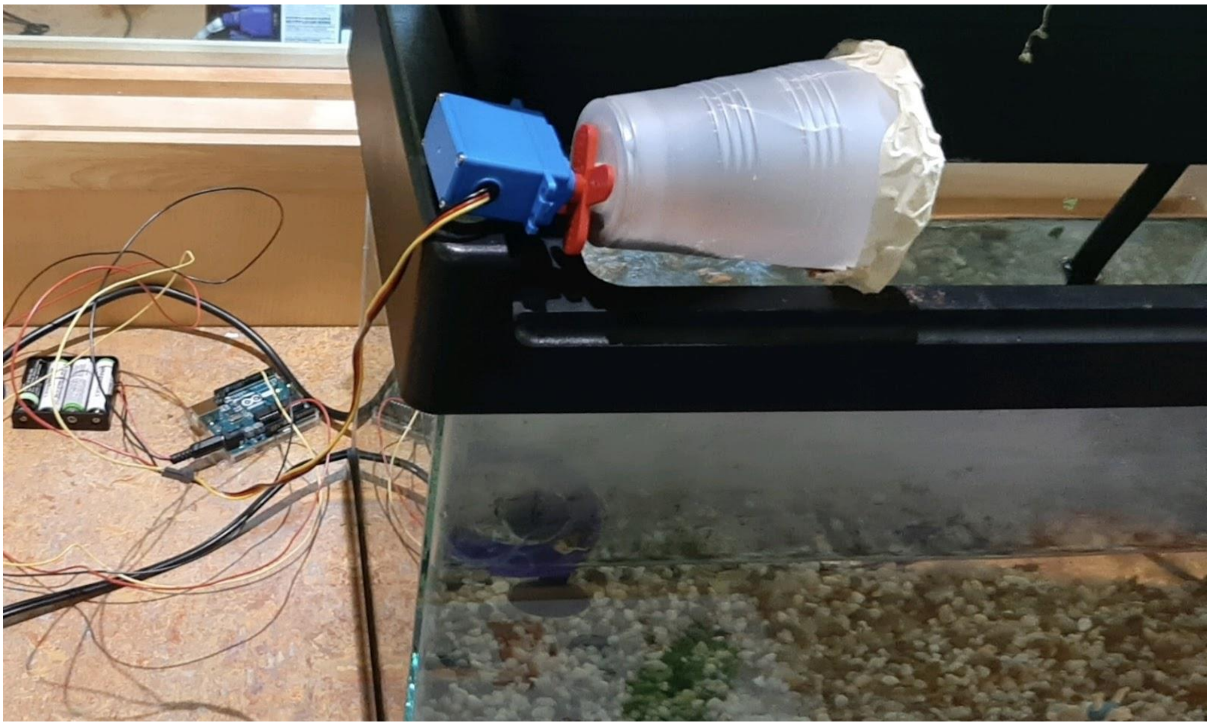

*Figure 4. The first prototype of the automated fish feeder. (Source: Author)*

*Figure 5. The second prototype for the automated fish feeder. (Source: Author)*

By the time that the summer workshop arrived the fish feeder was still inconsistent and needed work, so this became a design challenge for the youth who attended. They learned about algorithms by including mint and lavender infused oils (Figure 6) in their natural cosmetic recipes and products. This included explaining how infusing the lavender and mint into a carrier oils, like grapeseed oil, is a matter of extracting their volatile compounds. But to even grow the plants required them to be fed with water and fish waste from the aquaponics system. I explained the problem that the fish needed to be fed on Sunday when the library was closed and introduced the solution of an automated fish feeder as a way to care for both the fish and plants who were helping teach about algorithms. The children were then tasked with designing, building, and programming automated food delivery prototypes.

*Figure 6. Dried mint being infused into oil. (Source: Author)*

Part of the challenge was still figuring out what type of food delivery method would be most sufficient for feeding the fish. Based on the collaboration with the graduate student and youth patron, code for three possible servo motor actions for automated food delivery was modified from the Arduino code library and shared with children during the summer workshop. This included programs for “shake”, “dump”, and “rotate”. When this code was introduced, children had already learned about the “delay()” function and then learned about *for-loops*—a flow of control statement for repeating a block of code a specified number of times—for experimenting with the degrees and timing of the different possible motor behaviors. The children’s goal was to learn about how often fish need to be fed and how this would help the plants grow. They then built prototypes and manipulated the code to test methods for delivering the food to the fish using mini-aquaponics systems (Figure 7).

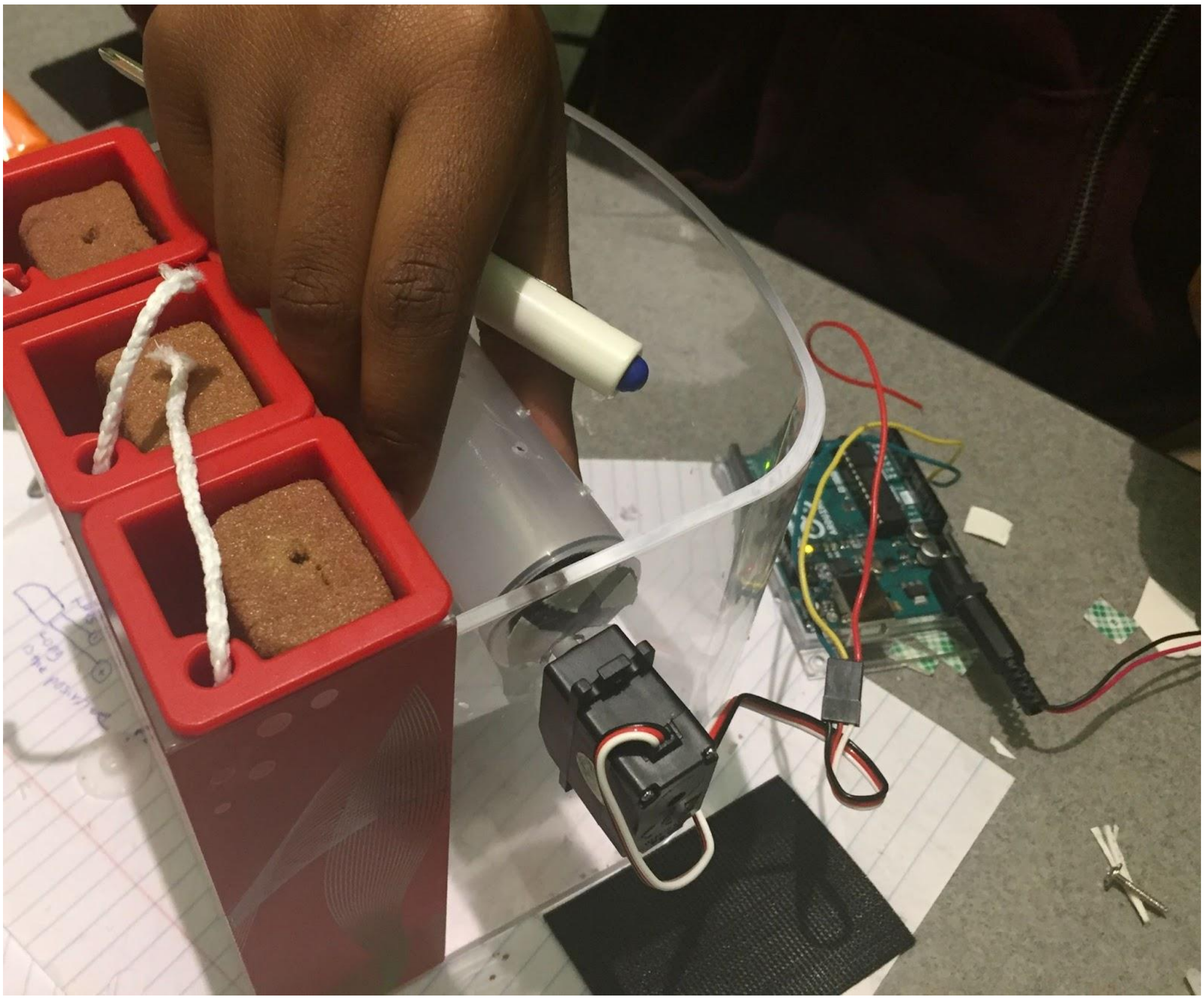

*Figure 7. A child designs their automated fish feeder prototype. (Source: Author)*

Here, a collaboration with the fish, plants, technology, and humans provided a foundation for computer science learning. Acknowledging the interconnectedness of the collaboration relates to what Kimmerer (2003) describes as the web of reciprocity, where everyone shares responsibility for themselves and others within larger ecological systems. The aquaponics system was set up so that the fish and plants would care for each other with help from the water pump system and humans who distributed food. Taking this multispecies collaboration seriously entered us into relationships that helped us to innovate computer science education at the library by attending to the needs of everyone involved.

But it needs to be noted that in the end none of the prototypes from either the research team or children turned out to be functionally consistent or reliable for the librarians. When the automated fish feeder did work it either delivered too much food or not enough. What turned out to be an interesting way for children to engage in webs of reciprocity and learn about for-loops still, at times, left the fish, lavender, and mint hungry or overfed. In contrast to webs of reciprocity and mutuality, Kimmerer (2013) introduces the concept of *collateral damage*. She describes collateral damage in terms of salamanders who are killed crossing a road humans drive on, human casualties of war for oil that fuel the cars, and the choices of herpetology students to not intervene in rescuing salamanders from the road so that they can collect accurate data on how many are killed to try and convince the highway department to make infrastructural changes that will protect future salamanders. Interconnection can be damaging as much as mutually beneficial. Was this computer science learning environment not based on a web of reciprocity at all, but a web that included overfeeding or underfeeding fish and plants as collateral damage? This was a sad lesson to learn upon reflection, but an important one for remembering that techno-vegetal collaborations must be based on iterative and ongoing negotiations to meet all collaborators needs during co-design.

*Intergenerational Learning: Multispecies Interactions & Plant-time*

While most of the librarians acknowledged that the aquaponics system set-up would have been unsustainable if not for researchers helping to clean and maintain it, they all discussed the educational opportunities that the system brought to the space. One highlighted the novelty of the system's temporal presence: "You know, we do a lot of one-time programs and you know, but any time we can do something, especially STEM [science, technology, engineering, and mathematics]-related that is, is a process that they can see over time [it] is wonderful." The plants gave children and adults something to keep up on from visit-to-visit and their sustained interest was helped by the fact that the system changed as fish were introduced and the plants grew (Figure 8); even after it was removed the librarians continued to report that patrons asked about it, suggesting the system left multispecies traces in its absence. As described in more detail below, the temporal dimension of the system's extended presence was oriented around what Marder (2013) describes as plant-time, which not only shaped the librarians' and library patrons' perceptions of the system itself but the whole library space.

*Figure 8. Mint and lavender growing together in the plant bed. (Source: Author)*

At first many of the librarians reported that they did not feel completely confident in explaining the design, function, and purpose of the aquaponics system. But as the plants started to fill out the bed and patrons started asking more questions the librarians turned to each other, the research team, books, and online sources to explain the system. One librarian explained that they found that caregivers asked the most questions: "Yeah, and a lot of the parents I've talked to about it who've come to my story times are very interested in, you know, showing their young ones how this is gonna work." Another librarian recalled one instance where a homeschool teacher incorporated the system into their lessons.

The librarians reported that children of all ages engaged with the system. But more so than middle and high school students who the system was designed to support during the summer workshop, it was younger children who the librarians experienced most often being drawn toward the system (Figure 9). They reported that children became emotionally and physically entangled with the aquaponics system, interacting with the fish, plants, and materials. For example, one librarian explained how she enrolled children in naming the fish: "Kids had a really good time figuring out what they wanted to name the fish. And then they were kind of excited, like drastically sad when we did or didn't pick the names they wanted." During the time that the system was set up, the librarians reported that they saw children greeting and waving goodbye to the fish and plants, playing with and picking the plants in the bed, sticking their hands in the water, and trying to capture guppies. The posthuman space of the aquaponic system was full of opportunities for children to become part of multispecies entanglements, growing and changing with the plants and fish themselves.

*Figure 9. The aquaponics system in the library. (Source: Author)*

Unlike many one-off programs that the library hosts, the multispecies interactions provided a sense of extended presence and unfolding iteration, change, and difference. It was this repetition that continued to engage patrons across generations, learning and experiencing the system together. Marder (2013) reminds us that:

> In plants, bursting out of themselves with every new copy of the leaf, nature stands out of itself—or else, ecstatically announces itself and temporalizes itself. Acts of repetition do not clarify anything whatsoever, do not consolidate or crystallize the structure of meaning they carry, but simply affirm, with renewed energy, the sense of vegetal existence, a sense which fuses with this very existence in all its heterogeneity and finitude. (p. 115)

The interactions with the plants and aquaponics system that the librarians reported on generally shows how the experiences of the library patrons became partially attuned to the repetitive and iterative aspects of plant-time and plant existence. But the unexpected and surprising differences from the plants were also about how the plants remained the same through self-similar and modular growth. Being entangled with plant-time not only shaped the library space but also the experiences of the space itself as it stayed the same but changed from visit-to-visit. This shifted the library trend from seeming to offer one-off programs to the inclusion of one that was ongoing and continually unfolding.

## Implications & Conclusion

Plants are part of teaching and learning in and out of classrooms around the globe. But accounting for plants' agencies and the traces of their corporeal rhetoric requires engaging with knowledge systems that challenge the Western tradition of treating plants as passive. In other words, it requires taking a plant turn. I have sought to provide theoretical and empirical support for turning posthumanist educational scholarship in post-zoocentric directions by introducing literature from Anishinaabe-gikendaasowin, plant science, and continental philosophy that attend to vegetal agencies and relationships. I sought to demonstrate the relevance of these literatures to posthumanist educational scholarship through multispecies storytelling about the design of a computer science learning environment at a library.

I introduced the concept of *techno-vegetal collaborations* to make posthuman space for vegetal life in collaborative human-nonhuman relational webs, specifically those that are about learning (e.g., Keune, Yankova, & Peppler, 2021). Storytelling about the plants' places within these webs and their unique growth time within the library reveals that they were not passive in co-design or learning, but actively shaping and being shaped by humans, other biotic nonhumans, materials, and technologies. And comparing and contrasting plant-memory and human-memory allowed me to challenge human exceptionalism while showing how plant-human interactions or perceptions of them affected the latter. Making space for techno-vegetal collaborations has implications for posthumanist educational scholarship and computer science education.

First, overcoming zoocentrism in posthumanist educational scholarship not only supports more dynamic multispecies relationships and projects, but can make reciprocity central to ethical accountability and computer science education itself. Indeed, my findings brought up ethical issues, specifically when put into the context of Anishinaabe-gikendaasowin and Kimmerer's (2003, 2013) discussions about the web of reciprocity and collateral damage. As Marder (2013) explains, plants have an ontology of giving. Thus, they can be easily exploited and treated in terms of collateral damage in the design of learning environments if their needs, which are always entangled with the needs of others (e.g., fish), are not cared for in a reciprocal relationship. Mutuality was the goal of the automated fish feeder project and activity, but if it was never met than can I truly make the claim that I was giving back as much as I was getting from the fish and plants? While asymmetries are inevitable, when entering posthuman co-design spaces and multispecies relationships, questions of ethical responsibility and reciprocal care must be continually asked and negotiated throughout the entire process. This is because collaborative relationships are not inherently beneficial to everyone involved.

This leads to the second implication. Treating plants as collaborators and contributors to the summer program became a generative opportunity to innovate computer science education. In this case computer science education was not imposed on plants but emerged from the relationships that I sought to establish with them. Not only are plants "free of any expectations of returns from the other" (Marder, 2013, p. 52) in their ontology of giving but this ontology also shaped and was shaped by computer science education in the automated fish feeder design challenge; accounting for their needs created an opportunity for computer science learning (though as noted above, the fulfillment of reciprocity is questioned). Computer science education researchers might indeed learn much from plants' inclusiveness and lack of expectations when designing learning environments that seek to bridge multiple domains. Key to this is respecting plants' agency and resisting views of vegetal passivity by being open to what they tell us when we listen and ask the right questions, without foreclosing the emergence of surprises and the unexpected. This is where posthuman collaborations make room for educational innovation. For example, given that one sign of plant intelligence is sensing and positioning in relationship to light (Trewavas 2014), how might we use motion sensors or photocells to help children learn to see plants as actors in and on the world? What new relationships might children form with plants when they learn to see their agency and traces of their corporeal rhetoric?

One limitation of this paper was that most human-plant interactions were secondhand accounts from human collaborators. While this provided unique data in and of itself, there was still more that could have been done to further a post-anthropocentric methodology. Future work might consider capturing video of plant and non-plant interactions, as well as from plants' spatial positionings (i.e., a plant's point of view). In addition to video of interactions, data about temperature, growing media moisture, and light might be collected using low-cost sensors. Bringing video and sensor data together might provide interesting insights and stories for making sense of how plants affect and are affected by others and their environments.

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