An interactive plant as a learning interface

Embodying environmental education in the natural environment

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***Abstract*— Research into environmental education has showed two components being important determinants of its effectiveness: a cognitive and an affective component. Cognitive learning usually takes place in a classroom setting and is about developing knowledge concerning environmental issues and action strategies. Affective learning mainly happens by physically experiencing nature and is about developing a sense of connectedness with nature. We present an innovative approach that integrates those two methods of learning in a free-choice learning setting. We augmented a living plant with interactive functionalities. By touching the plant, people can engage in a playful interactive dialogue that aims to teach them about the plant and its environment. It is hypothesized that this direct form of interaction positively impacts learning, because it enables an experience where people receive cognitive information, while they have an affective multisensory experience of nature. To test this, a study was done in a botanic garden. Two conditions were compared where visitors had the possibility to navigate through an interactive story by either (1) directly interacting with our "interactive plant", or (2) interacting with a tablet device that was placed in front of a plant. A pre-posttest design including observational measures was used with a sample of 37 visitors of a botanic garden in the Netherlands. Results show that both the tablet device and the "interactive plant" had a positive effect on the cognitive learning outcome. The results further show that the group that interacted with the "interactive plant" showed a significantly higher increase in scores on the multiple-choice questions, than the group that interacted with the tablet device. It seems that this difference in scores can be partly explained by the time that participants chose to interact with the test setup. Finally, results show that participants younger than 40 years chose to interact significantly longer with the interactive plant than with the tablet device. Participants older than 40 years showed no significant difference in duration of the interaction. This indicates that direct interaction with a plant manages to motivate a broader group of visitors to learn about nature. A bigger sample is needed to further assess the impact of direct interaction on free-choice learning at a botanic garden.**

***Index Terms*—Environmental education, free-choice learning, Augmented Reality, interface design, human plant interaction, experiential learning, affective learning**

I. Introduction

The increasingly visible impact that human development has on the environment highlights the need for an urgent transition to a more sustainable use of our planet. One of the obstacles in this transition, is motivating people to change their behavior to be more pro-environmental. Many studies have been done to find the main determinants of pro-environmental behavior (Palmer et al., 1999; Duroy, 2005; Hines et al., 1987; Robert & Bacon, 1997; Littledyke, 2008). All show that a combination of cognitive (e.g. knowledge of environmental issues and action strategies) and affective factors (e.g. experiences that cause people to give positive emotional value to and a sense of responsibility for nature) are needed for change in behavior. Other studies (Pesoa, 2008; Immordino-Yang, 2007; Jones & Issroff, 2004) show that the affective and cognitive domain are not separate actors in this, but they rather work together and amplify each other to control thought and behavior. For environmental education to be most effective, it seems that these domains should be integrated, transferring cognitive knowledge about nature while people have affective experiences with nature (Plass & Kaplan, 2015).

Nature areas are generally considered to be suitable locations for effective environmental education, as they offer the possibility to affectively experience nature. Dunn et al. (2006) argue that the future of nature conservation depends more specifically on urban nature, since a growing proportion of the world's population lives in cities:

"Although most ecosystems and species will not be saved in cities, their conservation may depend on the votes, donations, and future environmental leadership of people in cities; so, in the end, a great deal depends on urban nature. The urban jungle, with its many non-native species, may well be the breeding ground for future environmental action. What that urban jungle looks like, and how people interact with it, deserves more attention."

This raises the question to how urban nature should be used to effectively stimulate future environmental action. Botanic gardens, which offer accessibility to a high ecological diversity, often in (or close to) urban areas, have proven to be a suitable setting for environmental education. Multiple studies (Halpenny, 2006; Sellmann & Bogner, 2013, Braund & Reiss, 2004) have found that environmental education programs were more effective when performed in a botanic garden, than when performed in a classroom. Different approaches to learning at a botanic garden exist: a formal approach and a free-choice approach. The formal approach is similar to learning in a traditional classroom, where learners are guided through the educational program by a teacher. Although this method can be very effective (if the teacher is capable) it is time intensive and costly, thus making it only accessible to a limited amount of people, for a limited amount of time. In the free-choice approach, learners decide for themselves what, when and how they learn. Research (Falk, 1999; Leinhardt, Crowley & Knutson, 2002; Falk & Storksdieck, 2005) has shown this to be an effective method for educating visitors of science centers. Traditionally, botanic gardens use written signs and displays to facilitate free-choice learning. While this positions cognitive information within a natural environment that people can affectively experience, it is not guaranteed that visitors integrate these elements for an effective learning experience. A study by Ballantyne et al. (2008) shows that visitors of a botanic garden (Brisbane, Queensland) have a relatively low level of interest in learning about nature conservation. According to their study, visitors visited botanic gardens mainly for affective reasons, such as the enjoyment of the garden's aesthetic features. Ballantyne et al. conclude their research by saying:

"Our findings suggest that if botanic gardens are to introduce more educational activities that focus on conservation, they need to give careful consideration to how these are designed and promoted. As visitors are rarely highly motivated to learn, activities with a strong educational emphasis are unlikely to appeal."

While these findings must not count for all botanic gardens, it shows that at least for some types of visitors there is a need to develop other ways to transfer knowledge about the environment. Ways that don't have a strong educational emphasis, but connect more to the affective and experiential reasons for which visitors go to a botanic garden.

Multiple studies in the field of Augmented Reality (AR) (Kamarainen et al., 2013; Gardner et al., 2008; Huang et al., 2016; Uzunboylu et al., 2009) have presented and evaluated systems that look for new ways of integrating educational content in natural environments. In AR, computer-generated virtual objects are layered on a direct or indirect view of a physical real-world environment or object (Milgram & Kishino, 1994). These virtual objects can consist of different sensory inputs such as images, texts, audio and tactile feedback (Wu et al., 2013; Schraffenberger & van der Heide, 2014). By this, advanced AR technology allows users to add digital information to the surrounding real world and make them operable (Huang et al., 2016).

Previous studies have named AR as a likely candidate to become a key educational tool in the coming years (Johnson et al., 2010; Dede, 2009). Separate studies claim that AR can increase learning effectivity and motivation by: (1) providing users with immersion, presence and immediacy (Squire & Jan, 2007), (2) integrating formal and free-choice learning (Sotiriou & Bogner, 2008), (3) relating abstract concepts to real-world experiences (Dunleavy et al., 2009), (4) providing ubiquitous learning (Dunleavy et al., 2009) and (5) learning real world object observation and recognition (Chen et al., 2011). The assumption that founds these claims is that AR is good at connecting cognitive knowledge about a subject to the multimodal perception of the subject. However, in our view, these studies put too little focus on testing how the interaction with an educational AR system should be designed to most effectively integrate perception and knowledge. These studies all use some sort of interface (either a headset, tablet or phone) through which users can look at the environment and see additional content, layered on top of real objects (e.g. plants, soil and water) in the environment. While this does integrate the content more into the environment than traditional written signs do, the focus is very much on the technology that is used for the augmentation. In order to get the augmented content, users have to actively engage with the interface that is in between them and the environment (or the objects) that they learn about. This possibly distracts from physically experiencing the environment. It therefore possibly hampers the development of an affective connection to the environment. This raises the question if this type of AR-assisted environmental education facilitates the affective experience of the environment, or that it mainly facilitates the affective experience of the AR device, instead of the environment.

We present an innovative approach in which we, instead of providing visitors of a botanic garden with an interface through which they look at the environment, turn the environment itself into an interface. We augmented a living plant with interactive functionalities. By touching the plant, visitors can engage in a playful interactive dialogue that aims to teach them about the plant and its environment. It is hypothesized that this direct form of interaction positively impacts learning, because it allows visitors to keep their focus on the affective multisensory experience of nature whilst receiving cognitive information about nature. Furthermore, we hypothesize that the idea of interacting with a living organism engages people into the experience, causing both a higher attention for and addressing a higher value to the information being transferred, as such effects have been mentioned in other studies (Lee et al., 2015; Cira et al., 2015). To test these hypotheses, we set up a study that aims to answer the following research question:

Does using a touch sensing living plant as a user interface for an interactive learning experience increase visitor learning in a botanic garden?

In order to test the effect of the direct human-plant interaction, two groups were compared. Visitors had the possibility to navigate through an interactive story by either (1) directly interacting with our "interactive plant", or (2) interacting with a tablet device that was placed in front of a plant. A pre-posttest design including observational measures was used with a sample of 37 visitors of *De Hortus Botanicus*, a botanic garden in the Netherlands.

II. Materials and methods

A. Design and development of an interactive plant

The interactive plant was designed by using a using a sensor system and a living *Dracaena fragrans* (See figure 1). The system senses the vicinity of people and the location at which the plant is being touched. The system responds to touch by playing back sounds and recorded texts through a speaker built into the plant's pot. As visitors approached the plant, it started talking to them and asked them questions. Visitors could answer the questions by touching the plant. Touching different parts of the plant triggered different responses. By this, the interactive plant and visitors engaged in an interactive dialogue. The design of the setup used by the control group differed from this, only in that visitors controlled the dialogue by touching a tablet device, instead of the plant.

1) Content:

The dialogue was written in first person to personify the plant and thereby strengthen the affective component of the interaction. The story followed a narrative where the plant explained which ecosystem services it provides and the role its different parts play in providing those services. At fixed points in the narrative, the plant asked questions or directed participants to perform certain actions, which participants were able to answer by touching either the plant's soil, stem or leaves.

A spoken dialogue was the only way of communicating with the participants. Therefore, its content, structure and tone were important factors in our study. We iteratively designed and tested the dialogue and interaction over the course of 6 weeks prior to the research. Both usability tests and expert reviews were done with visitors and employees of the botanic garden. Based on feedback from these tests, we adjusted (1) the length and speed of the dialogue, (2) the phrasing of sentences, (3) the length of pauses between different sections of the dialogue, (4) the tone of voice, (5) the amount and (6) the type of interactions. This led to a narrative with a total length of 3:20 minutes, which was divided into 8 chapters, each ranging from 5 to 48 seconds in duration. At the end of each chapter, the plant asked a question to motivate participants to interact with it. Three different types of questions were implemented: (1) questions that ask subjects to correctly appoint parts of the plant in which specific processes take place (for example "identify which of my parts have a role in purifying air") (3 items), (2) questions that ask to estimate the impact of one of the plant's ecosystem services by choosing between three quantitative options (for example "how much CO2 do you think all plants in the garden combined sequester annually?")(2 items), and (3) questions that direct the participant to perform a specific action (like closely inspecting a leaf, or smelling the soil) (3 items). Next to the main narrative, we implemented sentences with which the plant reacted to the actions a participant performed (or did not perform), in order to give him/her the impression that they were truly engaging in a dialogue with the plant. For example, when a participant touched the stem after the plant had asked to touch the part that it uses to take up water, it responded by saying "no, not with stem, try again!". If then, the participant touched the stem again, the plant reacted with a different sentence referring to the previous one: "you already tried my stem, why not try something else!". When no action was performed for a set time interval, the plant used different phrases to encourage the participant to perform an action and later repeated the question that it had asked earlier. When a participant performed the correct action, the plant acknowledged this and continued to the next chapter of the main narrative.

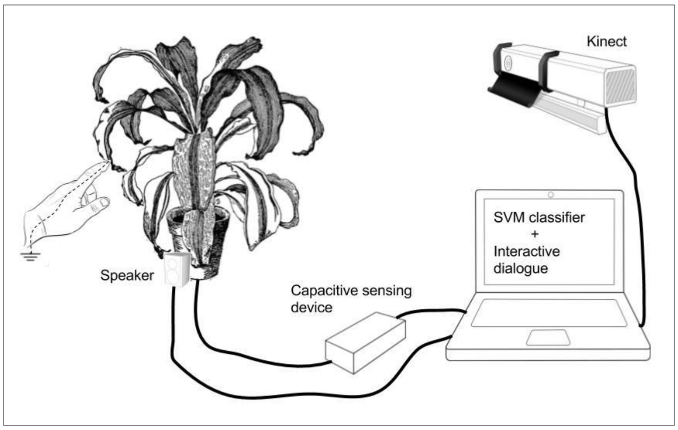

Fig. 1. Design of the test setup with the interactive plant.

We tried as much as possible to describe all the facts and numbers that were used in the narrative in ways that participants could easily relate to out of their own experiences. For example, when the plant talked about its size, it related to the size of the building that the participant was standing in; or when it talked about the amount of CO2 that it sequesters annually, it related to a number of times driving around the world with a car. This was done to enhance the experiential component of the interaction.

The first seven chapters contained the information that we tested for in our knowledge test. The eight (and final) chapter was implemented as a "bonus chapter", where participants were able to choose freely about which part of the plant they wanted to know more. By touching either the stem, leaves or soil, they could trigger a short fact on that part of the plant. The plant announced this final chapter by saying: "I have now told you about my most important features, if you want to know more, you can touch me anywhere". This was implemented to give a form of closure to participants that wanted to leave by that time, but also to give them the option to continue interacting with the plant. After a participant had played all the stories of the final chapter, the plant ended the dialogue by saying: "I have now told you everything I know, if you want to start over you can touch me again, otherwise: goodbye!". A Task Analysis of the interaction can be found in appendix I. A written script of the text that was used for the dialogue can be found in appendix II.

Next to spoken text, three different "background sounds" were created to associatively match the processes that take place inside the soil, stem and leaves of the plant. These sounds were played back continuously while a participant touched the corresponding part of the plant. Touching the soil triggered the sound of flowing water, touching the stem triggered the sound of bending wood and touching the leaves triggered the sound of wind chimes. This was implemented to always give the participants feedback when they touch the plant that was clearly audible, but did not interrupt the spoken dialogue. During the testing phase, visitors of the botanic garden enjoyed the feedback of the sounds and found the match between the sounds and plant parts to be intuitive.

2) Hardware design:

Two input devices were used in the setup with the interactive plant. One device was a self-built Swept Frequency Touch Sensing (SFTS) (Sato et al., 2012) device, that was connected to the plant's soil. This device was built using an Arduino microcomputer with a filtering circuit attached to it, as designed by DZL (2012). The Arduino's hardware clock was programmed to send out a square wave signal in a sweep of 160 different frequencies, from 1kHz to 3MHz. The filtering circuit removed noise from the signal, after which the signal entered the plant. After this, the capacitance of the plant for all the different frequencies was measured by the Arduino through the same circuit. This data was sent via serial communication to a computer running *Processing* (Reas & Fry, 2006). The other device that was used was a Microsoft Kinect 2, which detected participants' vicinity to the plant. This data was sent to processing via the OSC protocol.

For the setup of the control group, a tablet device was used as an input, instead of the SFTS device. The tablet ran an application that displayed a picture of the plant that we used for our setup (see figure 2B). The tablet sent the location at which the image of the plant was touched via OSC to the computer that ran the dialogue.

3) Software design:

An application, written in the *Processing* programming environment, received the data from both the Arduino and the Kinect 2. From the capacitive profile that it received from the Arduino, 217 features were extracted. These features consisted of:160 raw data points of the capacitive profile, 56 derivatives of the capacitive profile at three different levels of aliasing (in blocks of 5, 10 and 20), The maximizer of the capacitive profile

These data were used to train an SVM classifier (polynomial kernel, gamma = 1/217, C = 2), using a Support Vector Machines library for processing, based on *libsvm* (Chang & Lin, 2011). The SVM classifier was trained by feeding it live example data of someone touching the plant, labeled with the plant part that was being touched. After the classifier had been trained, it could distinct between: touching the leaves, touching the stem, touching the soil and no touch. The results from the trained SVM classifier were used to trigger events in the interactive dialogue.

The Kinect 2 was used to detect a participant's vicinity to the plant. If a participant entered within a distance of five meters to the plant, it would trigger the playback of samples that asked the participant to touch the plant in order to start the dialogue. If no one was detected within five meters of the plant, playback stopped and the interactive dialogue was reset to the beginning.

B. Experiment design

The study was based on a repeated measure design that included pre-test and post-test questionnaires, and observational measures. The questionnaires consisted of self-report items and closed and open-ended questions. The observational measures were taken by analyzing video recordings that were made while participants interacted with the test setup.

1) Setting:

The location of our study was *De Hortus Botanicus*, a botanic garden in Leiden, The Netherlands. The test setup was positioned on a table in the midst of other plants in a tropical greenhouse (see figure 2), about 300 meters from the entrance of the garden. Because of this distance, the participants had some time between filling in our questionnaires and interacting with our test setup. Upon entering the greenhouse, visitors would immediately pass by the plant, which in return would start talking to them. Subjects in the treatment group encountered the setup shown in figure 2a. Subjects in the control group encountered the setup shown in figure 2b.

2) Sample:

Over the course of six days, between May 29th and June 4th, visitors of the Botanic garden were asked to participate in the study just after they had entered the garden. A total of 172 visitors agreed to participate in the research and filled in a pre-test questionnaire. Of those, 127 also filled in a post-test questionnaire.

Before analysis, a total of 50 cases were removed from the dataset. Three of those were removed because those participants said they had interacted with our test setup during an earlier visit, before they filled in our pre-test questionnaire. Another 26 cases were removed from the dataset, as the video recordings that were made during the experiments revealed that the test setup was not functioning as supposed, due to technical errors. The remaining 21 subjects were removed as their test conditions differed considerably from the other

Fig. 2. A. (left) test setup for treatment group. B. (right) test setup for control group.

subjects, because they visited the garden as part of a school excursion. As we were interested in running our study with children in the age of 11 to 13, we had specifically contacted two schools that had planned an excursion to the botanic garden with three of their first-grade classes. We hoped to be able to test with these children under the same free-choice conditions as we did with our other participants, but this did not work out as intended. Due to time limitations and the school's own busy educational program, many of the students could not freely choose when to start and stop interacting with the setup. One of their teachers guided them to the setup and picked them up before the dialogue had ended, to continue the school's own educational program. One of the groups also openly complained when they needed to stay for another 10 minutes to fill in the post-test questionnaire after the school's program had ended. These observations, and the fact that this groups' data showed inconsistencies, led us to decide that these conditions were not representative for the free-choice learning setting that we wanted to study.

From the remaining group of subjects, we selected only the participants that had actually interacted with our setup by touching it. This resulted in a group of 37 participants. Of these, 13 female and 7 male participants interacted with the plant, 11 female and 5 male participants interacted with the tablet device (table 1).

In order to test for homogeneity between both test groups, we compared the pre-test data of the subjects. Table 2 shows that the participants in the control group scored significantly higher on the "effort" subscale of the IMI scale. Moreover, it shows that subjects in the treatment group scored higher on the knowledge test. These differences were not significant. However, a trend is visible in which the treatment group scores higher on the open questions. This means we unfortunately cannot assume homogeneity between the test groups. We will come back to this in the results section of this paper.

3) Methodology:

The basic research design consisted of questionnaires at the start and end of the participants' visit and of the analysis of video recordings that were made while participants interacted with the test setup. Figure 3 shows a time schedule of the experiment. The examiner sat at a table close to the entrance of the botanic garden. In order to randomly select participants, an imaginary line was drawn. Every first group of people to cross that line was approached by the examiner. If the group was Dutch speaking, they were asked "if they wanted to answer some questions in order to help us improve education in the botanic garden". If the visitors agreed on this, a brief explanation of the protocol was given. They were told that the pre-visit questionnaire consisted of questions on plants, nature and learning. They were also asked to consider filling in a second questionnaire at the end of their visit "to let us know what you thought about your visit". Finally, they were told that they would possibly be recorded on video "to measure the time that visitors spend at certain parts of the garden". An information form (see appendix III) was handed out to visitors

TABLE I. NUMBER OF MALE AND FEMALE PARTICIPANTS

n participants	Test	Control
Female	13	11
Male	7	5
Total	21	16

TABLE II. COMPARISON OF MEAN SCORES ON PRE-TEST QUESTIONNAIRES

		Test AVG ± SD	Control AVG ± SD	*p*
Demographics	Age	38.1 ± 22.3	42.9 ± 23.6	0.556
	Group size at entrance	2.8 ± 1.7	3.2 ± 1.7	0.432
	Group size during interaction	3.5 ± 2.7	3.2 ± 1.7	0.906
Prior knowledge	Self-report	2.98 ± 0.89	2.91 ± 0.97	0.987
	Open questions	2.50 ± 1.40	1.75 ± 1.24	0.093#
	MC questions	1.38 ± 0.70	1.22 ± 0.94	0.766
	Total	3.88 ± 1.72	2.97 ± 1.94	0.131
Nature relatedness	NR-6	3.71 ± 0.58	3.89 ± 0.58	0.422
Prior interest	Self-report	3.80 ± 1.02	4.11 ± 0.81	0.302
	IMI Competence	3.61 ± 0.58	3.67 ± 0.72	0.939
	IMI Interest	3.85 ± 0.49	3.98 ± 0.39	0.339
	IMI Effort	3.38 ± 0.67	4.07 ± 0.59	0.006*
	IMI Total mean	3.67 ± 0.42	3.90 ± 0.46	0.166

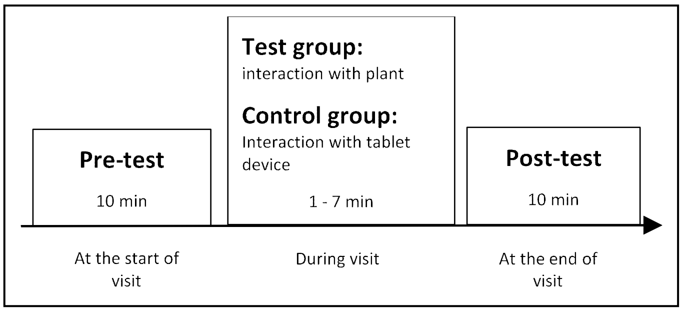

Fig. 3. Time schedule of the experiment.

that preferred a written explanation of the protocol. After visitors agreed to participate, they were given the first questionnaire and requested to fill it in without consulting any of the other participants.

The pre-test questionnaire (see appendix IV) consisted of three parts. The first part aimed to test the participants' prior knowledge and interest in topics that would be communicated by our test setup. The first two questions were open-ended. They asked the participants to name valuable services that plants deliver to humans, and to name the elements and parts that plants need to produce sugar. After that, two multiple-choice questions followed concerning the location at which basic processes in a plant take place. The fifth question asked participants to fill in the amount of CO_2, estimated in a number of times driving around the world with a car, that all the plants in the botanic garden combined sequester annually. The subsequent three questions asked the participants to rate (on a scale of 1 to 6) their knowledge (1 item) and interest (2 items) in Biology and plants.

The second part of the questionnaire consisted of 6 questions from the NR-6 scale (Nisbet & Zelenski, 2013) (see below for more information), aiming to measure the participants' sense of relatedness to nature. The third part of the questionnaire consisted of 10 questions from the "competence", "interest" and "effort" components of the Intrinsic Motivation Inventory (IMI) (Ryan & Deci, 2000) (see below for more information). This aimed to measure the subjects' prior motivation for learning in general. Additionally, subjects were asked for their age and gender. After they completed the pre-test questionnaire, the examiner wished them a happy stay and the participants were not contacted or guided at any moment during their visit.

The moment a participant entered the vicinity of the test setup, the video recording would start. This led to a total of 30 hours of video material. The recordings were made with the same Kinect device that was used to detect the proximity of participants to the test setup. This enabled us to record the internal audio from the computer that powered the test setup, in sync with the video. This allowed us to precisely monitor which parts of the interactive dialogue were heard by each participant, without the need to record any audio or conversations from the participants themselves. The recordings were analyzed at a later moment. We documented the time at which participants started and stopped to interact with the test setup, the chapters of the dialogue that they had heard, the number of people that were interacting with or listening to the test setup at the same time and the amount of times participants touched the plant and/or the tablet device. We further determined if the test setup was working as supposed and noted any additional information about the participants' behavior.

The moment a subject exited the garden, the examiner approached him/her for a second time and asked him/her to fill in the post-visit questionnaire (see appendix V). 26% of the subjects refused or did not return to the researcher because they left through another exit at the other side of the garden. The second questionnaire repeated the knowledge part (2 open questions, 2 multiple-choice questions and 1 number estimation question) and the nature relatedness part (the NR-6 scale). Additionally, it asked if subjects checked any of the answers to the knowledge questions on the internet or asked any of the other visitors for it. It then asked if the subject had noticed our "talking plant", if he/she touched the plant or tablet, and if he/she listened to the dialogue. If subjects responded with "no" they were asked why, after which they could give the questionnaire back to the examiner. The subjects that did interact with the test setup were asked to fill in two more parts of the questionnaire. One part consisted of 6 Likert scale questions about the usability of the setup with the talking plant. It asked how well the system reacted to their touch, if they understood that they had to touch the system to navigate through the dialogue, if they felt secure to touch the system, if they could clearly hear what the setup was saying, if they understood what it was saying and how well they thought the system worked. They were also asked for any additional comments on the functionality of the setup. The final part of the questionnaire consisted of 16 questions from the "competence", "interest", "effort" and "value" subscales of the IMI scale. These resembled the questions in the pre-test questionnaire, but were reformulated to test how motivated the subjects were to specifically use the test setup.

4) Instrument:

As other studies (Falk & Storksdieck, 2005) have shown, learning outcomes can be very diverse and are sometimes difficult to assess. We aimed to measure three different aspects of learning in this study: changes in a visitor's knowledge of plants and environmental processes, changes in a visitor's sense of connectedness to nature, and a visitor's subjective experience of learning with the test setup. Since other studies (Sellman & Bogner, 2013; Huang et al., 2016; Vos et al., 2011) have shown these three aspects to impact the effectivity of environmental education, we were interested to see how our two test conditions impacted these. Of course, the depth in which these aspects were measured was limited by the constraints of a free-choice learning setting, where participants are only prepared to spend limited time and effort on the assessment process. Since the aim of this study was to get an overview of the effects of our test setup on three different aspects, we opted to only use questionnaires for the assessment. For the knowledge measures, we focused mainly on factual knowledge and conceptual change. However, a range of other measurement techniques exist that, in addition to questionnaires, can reveal effects on other aspects of learning. Falk and Storksdieck (2005) for example used a combination of interviews and personal meaning mapping, a method where participants are asked to draw mind maps, to test visitor learning in a science center. Although these methods are more time intensive, Falk and Storksdieck show that a combination of these different assessment methods gives a broader insight in learning. A similar form of cognitive mapping has also been used to assess children's connectedness to nature (Fisman, 2005). Testing for indirect indicators of nature connectedness, by for example analyzing participants' reaction in a staged situation where they are asked to quickly act when the plant endures stress (for example because it falls over), would also be interesting. This would capture a more intuitive aspect of the affective component than a self-report scale does. These additional methods could be incorporated in future studies that separately focus on either the participants' knowledge, their connectedness to nature, or their subjective experience. Furthermore, due to time constraints of our study, we only tested for the short-term learning effects. To get insight into the long-term effects, participants should be asked to do additional tests a couple of weeks or months after their visit.

a) Knowledge:

The knowledge part of the questionnaire was identical for the pre- and post-test questionnaires. It was based on the structure that Falk and Storksdieck (2005) used to test visitor learning at a science center and consisted of two open-ended questions, two multiple-choice questions and one question where subjects had to estimate a number. The content of the questions was based on questions from first grade Biology tests out of the widely used Dutch Biology school book *Nectar*, and adjusted to fit the information that our interactive plant aimed to convey. Questions on this level were comprehensible by the younger participants (starting at 11 years old) and proved challenging enough for the older participants. Since our two test setups differed in the way in which participants physically experienced the talking plant, the knowledge questions were chosen to test the understanding of the connection between processes in a plant and the role of physical properties of a plant in managing these processes. The two open-ended questions aimed to capture the change in visitors' overall understanding of the topics that our setup tried to convey. These were: the ecosystem services that plants yield for people and the role that a plant's parts have in providing these services. The two multiple-choice questions aimed to capture more specific factual knowledge about the location of basic plant processes. The number estimation question was used to both capture a change in factual knowledge that any of the subjects was unlikely to know before the intervention, and to capture how participants' ideas about the amount of CO2 that plants sequester deviated from reality.

b) Nature relatedness:

Many different scales exist for measuring peoples' affective connection with nature. Most of these are aimed at capturing peoples feeling of connectedness to nature, peoples' environmental attitudes, or peoples' tendency to display pro-environmental behavior. All claim to assess different affective components. The oldest and most widely used scale is the New Environmental Paradigm (NEP) scale, developed by Dunlap and Van Liere (1978). The authors claim (Dunlap, 2008) the scale is usable to capture a broad variety of affective components. Others (Mayer & Franz, 2004) have commented that it solely measures cognitive believes, not affective experience. There has been a similar debate (Perrin & Benassi, 2009) about the Connectedness to Nature Scale (CNS), by Mayer and Franz (2004). There further is the 2-MEV scale, by Bogner and Wiseman (2006), which is an adaptation of the NEP scale. The Inclusion of Nature in Self (INS) scale, by Schultz (2002), functions differently, as it asks respondents to report their connectedness with nature by choosing between six graphical representations of two overlapping circles. Mayer and Franz (2004) have commented on this scale that such a single item scale cannot be assessed for reliability and that some people might not be able to accurately report their relation to nature at such an abstract level. A more recently developed test is the Nature Relatedness (NR) scale, by Nisbet et al. (2008). It claims to be "a self-report measure designed to assess the affective, cognitive, and physical relationship individuals have with the natural world." In a comparative study (Nisbet et al., 2008), the authors claim that the NR scale is a better reporter of environmental behavior than some of the other scales that we mentioned. Nisbet & Zelenski (2013) developed a shorter version of the NR scale, called the NR-6 scale. The Connectedness to Nature Index (CNI) (Cheng & Monroe, 2012) is a scale specifically designed for use with children. Bragg et al. (2013) did a comparative study to the use of these scales with children. They recommend the use of the CNI scale with children between 8 and 12 years old, but conclude that its phrasing might be too childish for older people. Therefore, they recommend the use of the NR-6 scale with children of 12+ years old. Since we knew our participants would be in very diverse age groups, we opted for a scale that would be usable with both children and adults. We therefore chose to use the NR-6 scale. The fact that it's a relatively short scale, consisting of 6 statements, helped to save time for the other questions, while keeping the assessment time within 10 minutes.

c) Intrinsic Motivation:

Next to cognitive and affective results of our intervention, we wanted to compare the subjective experience that participants had while learning with our two test setups. The Intrinsic Motivation Inventory (IMI) (Ryan & Deci, 2000) is a widely used scale for assessing a participant's experience after performing a target activity. It consists of 7 subscales that each assess a different element of the experience. We selected the subscales: perceived competence (4 items), enjoyment/interest (4 items), effort (2 items) and value (6 items). Since the nature of our study caused us to have a diverse set of participants, we first wanted to assess, prior to our intervention, the subjective experience that subjects had with learning in general. After our intervention, we wanted to assess the experience subjects had with specifically our two test setups. We therefore used a version of IMI that was adapted for a pre- and post-test design by Vos et al. (2011), who used it to compare two different interactive tasks in an educational game. Where Vos et al. (2011) used a measure of participants' intrinsic motivation at school in their pre-test, we used a more general measure of the participants' intrinsic motivation for learning in general in our pre-test. This was done, so we could use it with a broad set of age groups.

d) Cueing bias:

Because of our use of a pre- and post-test design, there is the possibility of a cueing bias in our results. Previous studies in a similar setting that used more intrusive assessment methods such as interviews, did not find evidence for pre-visit interventions to significantly influence subject learning (Adelman et al., 2001; Falk & Storksdieck, 2005). We can however not rule out the possibility that this happened. We did develop our methodology in a way to minimize possible effects. During their entry interview, subjects were not told about the interactive plant or the possibility of encountering an educative element in the garden. They were only told "that we wanted to know more about visitors of the botanic garden, in order to improve education in the garden". Subjects were also not informed about the fact that part of the post-questionnaire would consist of knowledge questions. We simply said that we wanted to ask them some questions about their experience of the garden, at the end of their visit. Furthermore, to not make it too obvious that our research was completely focused on their interaction with the interactive plant, we tried to separate the location at which participants were surveyed as much as possible from the location of the interactive plant, by placing the plant in a greenhouse about 300 meters from the entrance. In the post-visit questionnaire, we asked if participants had looked up or discussed any of the answers to the questions from the knowledge part. 10% of the subjects responded that they did, indicating that there had been a cueing bias with at least a small part of the participants. The scores of these participants on the knowledge questions were therefore not used in the analysis.

5) Data analysis:

Data from the written questionnaires were transcribed and stored in a spreadsheet processing program. Data from the video recordings were annotated in the same spreadsheet, by the examiner that also took in the questionnaires on the testing days. Consecutively, the appropriate parametrical and non-parametrical statistics were used to analyze the data. These included Mann-Whitney U tests, one-sample Wilcoxon tests, one-sample t-tests, two-independent-sample t-tests, Spearman rank correlations, and chi-square tests. Analyses were done using Matlab and Matlab's Statistical Toolbox.

III. Results and discussion

A. Pre-post comparison of knowledge scores

The first thing that the results of our study show is that the subjects that interacted with either of our two test setups significantly increased their knowledge about the tested topics. The knowledge scores of the subjects that did not encounter any of our test setups show almost no difference between pre-test and post-test (see table 3). This supports the idea that the perceived increase in knowledge was caused by our intervention, and not by some other factors like educational content that was placed somewhere else in the botanic garden, or a cueing bias. The negligible change (< 5%) in scores of the subjects that did not encounter our setups further indicates that subjects were equally motivated to answer both pre-test and post-test questionnaires. Participants that interacted directly with the plant, significantly increased their scores on both open-ended and multiple-choice questions. Participants that interacted with the tablet device only significantly increased their scores on the open-ended questions. There is a trend in the increase of their scores on the multiple-choice questions, but this is not statistically significant.

B. Pre-post comparison of nature relatedness

Studies (Bogner & Wiseman, 2006) have shown that affective measures like nature relatedness are not easily changed in adults, especially not by a short intervention like we used. Other studies (Sellman & Bogner, 2013; Huang et al., 2016) have however shown that a one-day intervention can impact children's sense of relatedness to nature. In none of our test conditions significant differences were found between the subjects' relatedness to nature at the start and end of their visit (see table 4). This is not very surprising, considering the fact that most of our subjects were adults. Although we tried to have a bigger group of subjects within the age of 11-13, unfortunately it did not work out this way. It might also take a longer intervention to change nature relatedness. Studies (Sellman & Bogner, 2013; Huang et al., 2016) that showed an increase used an intervention that lasted at least a couple of hours. Hence, in order to further test for differences in the impact of our two test setups on subjects' nature relatedness, a bigger group of underaged participants and a longer intervention time would be needed. In future research, the intervention time could be extended by using a test setup with multiple interactive plants throughout the garden.

C. Differences in knowledge increase between tablet and plant

A comparison between our two test groups (see table 5) shows that the subjects that interacted with our interactive plant showed a significantly higher increase in multiple-choice test scores, than the subjects that interacted with the tablet device. There were no significant differences in the increase of scores on the open-ended questions. Multiple explanations can be given for these different effects on the two knowledge measures: (1) the interactive plant is more effective than the tablet in transferring only the specific type of knowledge that we tested for with the multiple-choice questions, (2) there is also a difference in learning on the open-ended question, which was not measured due to test effects, (3) some other effects exist. As table 2 shows, subjects in the treatment group scored higher on both the open-ended and multiple-choice questions in the pre-test at the start of their visit. Especially on the open-ended questions, there was a considerable difference in scores between the two conditions. Since subjects in the treatment group already knew more beforehand, there was less knowledge for them to gain by our intervention. Such a masking effect would prevent us from detecting differences in knowledge gain that were in reality there.

Despite the fact that the treatment group also scored higher on the multiple-choice questions in the pre-test (albeit by a small margin), they still showed a bigger increase in scores after the intervention. Hence, the question remains: what was the cause of the higher increase in scores on the multiple-choice questions in the treatment group than in the control group. One possible explanation is that direct interaction with the plant caused subjects to better store the (short-term) cognitive knowledge, than did interaction with a tablet device. The other explanation could be that participants spent more time with the interactive plant than with the tablet device and therefore were able to receive more information. In order to check this, we looked specifically at the chapters of the narrative that the participants had heard while they were interacting with the test setup. Chapters 4, 5 and 7 contained the information that we tested for with the multiple-choice questions, so we compared the scores of both groups, for only the subjects that had heard these three chapters. Table 6 shows that there were no significant differences in the increase in multiple-choice question scores for these cases. Making this selection left us with very small sample sizes of respectively

11 and 6 subjects in the treatment group and control group, so to truly assess this, a bigger sample size is needed. However, we can see that 64.7 % of the subjects in the treatment group heard chapter 4,5 and 7, while only 42.9 % of the subjects in the control group heard these chapters. It is likely that this was of influence on the increase in test scores. It thus seems that, in our test, the subjects that interacted directly with the plant learned more about the multiple-choice questions than the subjects that interacted with the tablet device, because more subjects chose to interact with the setup for a longer time and therefore received more of the information. This observation hints to the idea that participants that interacted with the plant were more motivated to hear its information, than the participants that interacted with the tablet. We therefore looked at differences in subjects' scores on the intrinsic motivation inventory.

D. Differences in motivations between tablet and plant

We compared the post-test scores in the "competence", "interest, "effort" and "value" subscales of IMI, and the mean score of all subscales of IMI. No significant differences were found between the subjects that interacted with the plant directly and the subjects that interacted with the plant through the tablet device (see table 7).

This could mean that the participants were equally motivated to interact with both setups. However, any possible effects could also be masked by the fact that the two test groups were not homogenous (see table 2). Since results on the IMI scores of the pre-test questionnaire show that subjects in the control group indicated to be willing to do more effort for learning in general, this could have created a bias in our post-test results in various ways. We therefore looked at correlations between IMI pre-test scores and IMI post-test scores and the interaction time. The correlation matrix in table 8 shows that, in the treatment group, there was a significant positive correlation between pre-test scores on the "effort" subscale and post-test scores on the "value" subscale and the mean total of the IMI score. We also see a strong trend in the positive correlation with the "competence" subscale. These correlations were not found in the control group, further highlighting the lack of homogeneity between the two test groups. With both test groups pooled, there was still a significant positive correlation between pre-test scores on the "effort" subscale and post-test scores on the "value" subscale, and a trend in positive correlation with mean total of the IMI score. It thus seems that visitors that are willing to put more effort in learning in general, are more likely to have a higher motivation for learning in the type of setting that we researched. Considering that the participants that interacted with the plant were willing to put significantly less effort in general learning than the participants that interacted with the tablet, makes the results of the learning motivation tests difficult to interpret. We therefore looked at differences in the time participants chose to spend with our two setups, as this is a likely indicator for their enjoyment of using the system, considering the fact that participants were free to choose when to start and stop

E. Differences in interaction time between tablet and plant

Table 9 shows that, for participants of all ages combined, no significant differences were found in the duration for which visitors chose to interact with the tablet or plant. However, a scatterplot of the age and the interaction time (see figure 4) reveals two interesting things. First, a Spearman rank test shows a significant positive correlation between the age of participants and interaction time. Thus, older participants generally engage longer in the activity than younger people. Second, there seems to be a difference in the distribution of the points of the two test groups between the participants that were younger than 40 years and the participants that were older than 40 years. Of the participants younger than 40 years, the ones that encountered the interactive plant seemed to generally interact longer than the ones that encountered the tablet. For the participants older than 40 years, it seems that the opposite was the case: the ones that encountered the interactive plant seemed to generally interact shorter than the ones that encountered the tablet. The statistical tests reported in table 9 partially support these observations. They show that participants younger than 40 years indeed interacted significantly longer with the plant than they did with the tablet. Participants older than 40 years, interacted on average longer with the tablet than with the plant, but these differences were not significant. Our limited sample size and the high variance in the data of mainly the 40+ age group prevent us from making firm conclusions. However, these results indicate that the direct plant interaction works particularly well to motivate younger people to learn about the plant. Older people seem to generally have a high motivation to learn, the type of interaction being of less influence. This supports the idea that the interactive plant manages to speak to a broader group of visitors than the tablet device does.

F. Observations and participants' comments

Next to the results of the quantitative tests, we believe that our observations of participants' comments and behavior also indicate that some groups of visitors found the interactive plant more enjoyable to interact with than the tablet device. Both the reactions that we observed while reviewing the video material and the comments participants made about the two setups, give some insight.

Of the participants that interacted with the plant, many made positive remarks after filling in the post-questionnaire, some also wrote down comments. One participant said he found it "very nice and interactive!" and was "curious how it worked", indicating that he liked the interactivity and wondered how the plant could sense their touch. Another participant wrote "very nice idea! Especially for kids", indicating that she enjoyed it, but found it maybe more suitable for kids that for herself. In the group that interacted with the tablet, no such positive comments were made, while three people commented that "it took too long".

Another difference between the two conditions seems to be highlighted by one subject that interacted with the plant and commented that "he did not get it at the beginning". This indicates that the novelty of our approach may confuse people or make them feel insecure to use it in the beginning. We also observed this in the video recordings. Participants that encountered the interactive plant were generally a bit careful at first. However, after they had interacted with the plant for some time and clearly noticed that the it reacted to their touch, many showed indications of wonder and enjoyment. For example, they called their friends or relatives to join, or looked around to see if there was a person controlling the plant's speech. Some participants even started talking to the plant or made funny faces towards it, indicating that they approached the plant as if it was a person that they interacted with. The recordings of the participants that interacted with the tablet did not show such signs of enthusiastic or social behavior. Within this group, there seemed to be a distinction between age groups that matches the distinction with regard to the duration of the interaction that we described in the previous chapter. Generally, people older than 40 years who saw the tablet, touched it without hesitation and stood next to it closely listening to the story, without showing clear signs of enthusiasm or "social behavior" towards the plant. These seemed specifically interested in learning and not so much in the playful interactive element. Generally, people younger than 40 years showed a sign of disinterest (for example by shrugging their shoulders) and walked away, after they had had a few moments of interaction. It seems these persons were interested in a playful interaction and not only in learning. After finding that the interaction was not so interesting to them, they decided to leave. This may have been the case because an interaction with a tablet was already very familiar for them and not surprising enough.

These observations indicate that there are big differences between visitors' motivations to go to a botanic garden. For people that are actively looking for a learn opportunity, the tablet device might have been a familiar indicator of an object that contains educational content, as it is commonly used for educational purposes in free-choice learning settings. The interactive plant might, at first sight, have been more an indication of a game element and not so much of an educational element. These differences in initial perception of the setup might have changed the way the participants engaged with it and subjectively experienced it. Furthermore, it might have influenced which type of visitors started interacting with which setup in the first place, thus explaining why we found the group of participants that interacted with the tablet to be more willing to put effort in general learning. This shows that comparing different educational objects in a free-choice learning setting is a complicated endeavor. Different people have different needs and different setups can fill different needs. Our interactive plant did show to be an effective tool for motivating botanic garden visitors to learn about nature. Further research is needed to determine if it can truly speak to a broader group of people, both those that are interested in learning and those that are interested in a playful element.

G. *Reflections on the content and design of the interactive plant*

Overall, participants of varying ages seemed to like and understand the content of the dialogue. The increase in scores on the knowledge test and the comments of children as young as 10 years old showed that they understood most of it, except for some difficult words, like "photosynthesis". The fact that most of the adult participants scored lower than 4 out of 10 points on the knowledge test prior to their visit shows that the content was challenging enough for them.

Our experiment, however, also revealed some aspects of the content of the interactive plant that did not come up during the user tests that we did prior to the experiment. Some of the content of the dialogue appeared to speak to visitors very much, while other content appeared to not speak to them. Multiple participants specifically mentioned that they liked the part on the amount of CO2 that the plant sequesters annually (given in a number of times driving around the world with a car) very much. The question assessing this knowledge also showed the highest increase in correct answers of all the knowledge questions. Such content apparently triggered participants to pay attention. Possibly because they could easily relate to it, because it was very concrete factual knowledge that directly related to the specific location and activity that the participants were doing. The content also placed participants' own actions (driving cars) within the context of a widely known and relevant environmental problem (too much CO2 emissions). Additionally, it emphasized the relevance of the activity (learning about plants), by explaining the role plants have in countering too high CO2 emissions. However, the content about the plant's ability to remove toxic compounds from the air, which was conceptually similar to the part about taking up CO2, did not grab the participants' attention. Almost none showed a learning effect on this topic in the knowledge test. A reason for this could be that this content was given at the start of the dialogue, where participants were mainly focusing on figuring out how to interact with the system, instead of on the content itself. Another reason seems to be that the concept of "removing toxic compounds from the air" was confusing to them. Answers on the knowledge tests of multiple participants showed that they thought that this process was the same as taking up CO2 from the air, which is not what we meant. Pre-visit knowledge test shows that almost none of the participants knew about the existence of a plant's ability to remove toxic compounds from the air. It seems that therefore, they linked that information to another, much wider known, concept: the process of taking up CO2. This indicates that, in the future, clearer distinctions between conceptually similar content should be made to prevent misconceptions from emerging. In order to correctly do this, it should be taken into account which are the most frequently occurring misconceptions that visitors have about the topics, in order to correctly address and change these misconceptions.

The experiment also showed that some improvements could be made with regard to the design of the setup and the length of the dialogue. The core educational content was communicated by the interactive plant during the first 3,5 to 4,5 minutes (depending on the choices participants made during the interaction) of the dialogue. As figure 4 shows, part of especially the younger participants did not engage in the dialogue long enough to receive all this content. If the dialogue length would have been about 2,5 minutes, almost all participants would have stayed for long enough to receive all the content. Multiple participants commented that they would had preferred to learn by having shorter interactions with multiple plants, instead of a longer interaction with one plant. Thus, it seems that, in order to motivate visitors to put more of their time in the activity, multiple interactive plants that each have a maximum dialogue length of 2,5 minutes should be used.

TABLE III. COMPARISON OF PRE-TEST AND POST-TEST KNOWLEDGE SCORES

Group	Question type	Pre-test	Post-test	Mean difference	Mean change	*p*
Plant	Open questions[a]	2.50	3.47	0.97	38.8 %	.000**
	MC questions[b]	1.38	2.76	1.38	100 %	.000**
	Total[c]	3.88	6.24	2.36	60.8 %	.003*
Tablet	Open questions[d]	1.75	3.08	1.33	76 %	.004*
	MC questions[e]	1.22	1.73	0.51	41.8 %	.09[#]
	Total[f]	2.97	4.81	1.84	62.0 %	.004*
No plant & no tablet	Open questions[g]	2.48	2.44	-0.04	-1.6 %	.162
	MC questions[h]	1.61	1.56	-0.05	-3.1 %	.890
	Total[i]	4.09	4.00	-0.09	-2.2 %	.677

T-test results: $t^a(16) = -4.20$; $t^b(16) = -7.71$; $t^c(16) = -7.04$; $t^d(13) = -3.51$; $t^e(13) = -1.85$; $t^f(13) = -3.45$; $t^g(24) = -1.44$; $t^h(24) = .14$; $t^i(24) = -0.42$. $^{\#}$ $p < .1$, * $p < .01$, ** $p < .001$.

TABLE IV. COMPARISON OF PRE-TEST AND POST-TEST NATURE RELATEDNESS (NR-6) SCORES

NR-6 mean scores	Pre-test	Post-test	Mean difference	Mean change	*p*
Plant	3.71	3.65	-0.06	-1.6 %	.817
Tablet	3.89	3.92	0.03	0.8 %	.869
No plant & no tablet	4.03	3.97	-0.06	-1.5 %	.656

T-test results: $t^a(15) = -.24$; $t^b(13) = -.17$; $t^c(25) = .45$.

TABLE V. COMPARISON OF GAIN IN KNOWLEDGE SCORES BETWEEN TEST GROUP (PLANT) AND CONTROL GROUP (TABLET)

Knowledge gain	Plant AVG ± SD	Tablet AVG ± SD	*p*
Open questions	0.82 ± 0.81	1.07 ± 1.14	0.485
MC questions	1.35 ± 0.72	0.57 ± 1.16	0.029*
Total	2.18 ± 1.27	1.64 ± 1.78	0.339

T-test results: $t^a(29) = -.71$; $t^b(29) = 2.30$; $t^c(29) = .97$. * $p < .05$

TABLE VI. COMPARISON OF GAIN IN MULTIPLE-CHOICE (MC) KNOWLEDGE SCORES BETWEEN SUBJECTS OF TEST GROUP (PLANT) AND CONTROL GROUP (TABLET) THAT HEARD CHAPTERS 4,5 AND 7 OF THE NARRATIVE

Knowledge gain	Plant	Tablet	*p*
Nr. of subjects that heard chapters	11	6	
Nr. of subjects in group	17	14	
% of subjects that heard chapters	64.7%	42.9%	
MC question score gain AVG ± SD	1.00 ± .89	1.17 ± .75	.705

T-test results: $t^a(15) = -.39$.

TABLE VII. COMPARISON OF POST-TEST SCORES ON INTRINSIC MOTIVATION INVENTORY (IMI) BETWEEN SUBJECTS OF TEST GROUP (PLANT) AND CONTROL GROUP (TABLET)

IMI AVG ± SD	Plant	Tablet	*p*
Competence[a]	3.84 ± .50	3.70 ± 0.67	.504
Interest[b]	3.88 ± .66	3.98 ± 0.62	.670
Effort[c]	3.12 ± .76	3.07 ± 0.70	.863
Value[d]	3.84 ± .62	4.01 ± 0.66	.464
Mean total[e]	3.67 ± .51	3.68 ± 0.50	.977

T-test results: $t^a(29) = 0.68$; $t^b(29) = -0.43$; $t^c(29) = 0.17$; $t^d(30) = -0.74$; $t^e(29) = -0.03$.

TABLE VIII. CORRELATION ANALYSIS (SPEARMAN RHO) OF PRE-TEST AND POST-TEST SCORES ON INTRINSIC MOTIVATION INVENTORY (IMI) SUBSCALES: COMPETENCE (COMP), INTEREST (INT), EFFORT (EFF), VALUE (VAL) AND INTERACTION DURATION (INT DUR)

Group	IMI subscale	COMP post	INT post	*EFF post*	*VAL post*	*TOT post*	*Int dur*
Plant	COMP pre	.13	-.22	-.33	*-.27*	*-.22*	*-.11*
	INT pre	*.54**	*-.05*	*-.02*	*.25*	*.20*	*.05*
	EFF pre	.49[#]	.26	.27	.50*	.56*	.14
	TOT pre	.52*	-.09	-.03	.15	.19	.03
Tablet	COMP pre	.129	.06	-.04	.19	.11	-.11
	INT pre	-.06	.62*	.02	.62*	.30	-.02
	EFF pre	-.01	.20	-.12	.36	.15	-.29
	TOT pre	.05	.20	-.05	.36	.17	-.15
Plant + tablet	COMP pre	.15	-.10	-.19	-.03	-.03	-.03
	INT pre	.28	.20	-.03	.38*	.22	.01
	EFF pre	.20	.18	.13	.43*	.35[#]	-.1
	TOT pre	.26	.06	-.00	.30	.22	-.06

$^{\#}$ $p < .1$, * $p < .05$, ** $p < .01$.

TABLE IX. COMPARISON BETWEEN DURATION OF INTERACTION (INT DUR) OF TEST GROUP (PLANT) AND CONTROL GROUP (TABLET), SEGMENTED BY AGE

Int dur AVG ± SD	Plant	Tablet	*p*
All ages[a]	218.40 ± 89.97	219.63 ± 168.70	.978
Age < 40[b]	199.00 ± 84.69	118.56 ± 63.42	.030*
Age > 40[c]	242.11 ± 95.44	349.57 ± 175.39	.138

T-test results: $t^a(29) = 0.68$; $t^b(29) = -0.43$; $t^c(29) = 0.17$; $t^d(30) = -0.74$; $t^e(29) = -0.03$.

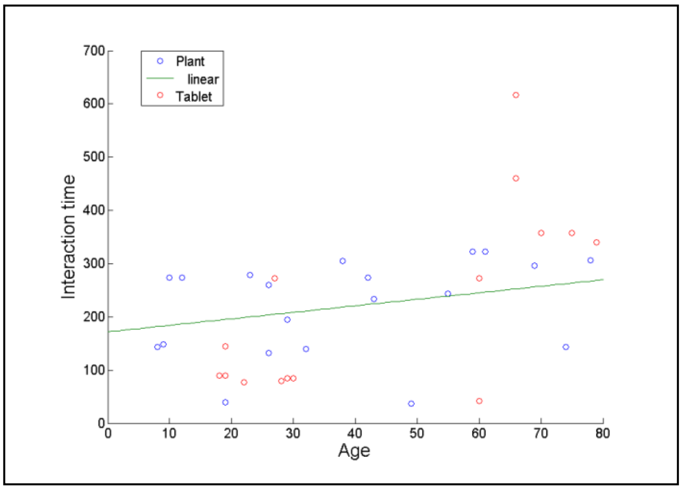

Fig. 4. Scatterplot of participant age and interaction time (s). Correlation analysis: Spearman rho = .51, p = .002

IV. Conclusion

In this study, we set out to gain a deeper understanding into free-choice environmental education. We developed a novel approach that uses an interactive plant to embody educational content about the environment in the natural environment of a botanic garden. The following question was asked:

Does using a touch sensing living plant as a user interface for an interactive learning experience increase visitor learning in a botanic garden?

First and foremost, it is important to note that visitors that interacted with our plant did learn about nature. Our sample consisted of a diverse range of people, with varying ages, varying motivations to visit the garden and varying knowledge of Biology. Most of the participants showed some sign of increased knowledge on the tested topics. We further found that visitors that directly interacted with our plant showed a higher increase in scores on the multiple-choice questions than the visitors that interacted with a tablet device that was placed next to the plant. Thus, using a touch sensing plant as a user interface did at least increase the type of short-term cognitive learning that was captured by the multiple-choice questions. It seems likely that this was due to the fact that the visitors younger than 40 years were willing to interact for a longer time with the plant than with the tablet device. Because of this, they received more of the educational content. This, combined with the comments that visitors made on the two setups, gives the impression that especially younger people found directly interacting with a plant to be more interesting and exciting, than interacting with a tablet device.

However, the design and nature of the setting used in our study, makes it difficult to determine what the exact causes of the perceived effects were, and thus which exact learning benefits directly interacting with a plant yields over interacting with a tablet. Researching a free-choice learning setting means that you want to intervene as little as possible in the participants' learning experience. This limits the amount of control over the selection of participants and the conditions under which the experiment takes place. To tease out individual effects, the visitor group should be segmented based on factors such as, age, prior knowledge and prior motivations. Unfortunately, our efforts to target the more specific age group of first-grade students proved unusable due to inconsistencies in the test procedure. Next to that, we lacked insight into visitors' knowledge and motivations before the experiment. Segmenting the sample based on these factors after the experiment diminished our analytical powers. Although we tried to get a sufficient sample size by surveying 172 visitors, only a small fraction of those proved usable to find specific effects of the type of interaction on the knowledge that people gain. Therefore, in the future, we should put more focus on collecting specific data from a homogenous group of visitors and increase the sample size

To further aid studying individual effects, additional assessment methods could be used. We were limited by the constraints of a free-choice learning setting, where visitors are only willing to spend limited time and effort on the assessment process. Since this study aimed to get a general view on the effect of our intervention on three different components (the participants' knowledge, their connectedness to nature and their subjective experience), we opted to only use questionnaires for the assessment. However, a range of other measurement methods exist that, in addition to questionnaires, could reveal effects on other aspects of learning. These additional methods could be incorporated in studies that separately focus on either the participants' knowledge, their connectedness to nature, or their subjective experience

Our observations on the design of the interactive plant showed that the content of the dialogue appeared to speak to most of the visitors, regardless of their age. Mainly the parts that placed both the participants' personal experiences and the information about the plant within a broader context of the environmental issues grabbed their attention. One part seemed to cause a misconception, as some participants mixed up the information on two different, but conceptually similar, topics. In order to prevent visitors from getting misconceptions, some parts of the content should make clearer distinctions between conceptually similar topics. To design content that correctly address and change these misconceptions, it should be taken into account which are the most frequently occurring misconceptions that visitors have about the topics.

Finally, we found that, for some of the younger visitors, the duration of the dialogue was a bit too long. To better suit the short attention span of this younger age group, future studies should use a setup with multiple interactive plants that each convey the educational content within 2,5 minutes. Placing multiple test setups throughout the garden, each having different educational content, could increase the total time that participants are willing to spend on the interaction and thereby (1) enhance the test effects and (2) give participants more time to get used to the interaction. A setup with multiple plants would also (3) increase the likeliness of participants to encounter the setup and (4) increase participants' freedom of choice.

This study proved helpful in getting a general overview of the short-term learning effects of an interactive plant. We believe that the system that we developed offers interesting new perspectives on the use of AR in free-choice environmental education and on its use in free-choice education in general. Teaching people about real-world objects by using these objects as a direct interface for controlling an interactive learning experience can emphasize the experiential and affective perception of those objects. This study indicates that it is effective at motivating a broad group of people of varying ages, knowledge and interests, to learn about nature. It would therefore be worthwhile to take such a method into account when developing free-choice learning facilities in the future. Our study also opens the door to a field of educational research that aims to assess the role that different methods of interaction have in developing AR systems that assist learning. More knowledge on this is needed in a time where free-choice learning takes in an increasing role in educating a diverse set of people. Especially if this knowledge can contribute to aiding a world that desperately needs a more sustainable use of its environment.

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