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# An Interactive Robotic Fish Exhibit for Designed Settings in Informal Science Learning

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***Abstract*—Informal science learning aims to improve public understanding of STEM. Free-choice learners can be engaged in a wide range of experiences, ranging from watching entertaining educational videos to actively participating in hands-on projects. Efforts in informal science learning are often gauged by their ability to elicit interaction, to foster learning, and to influence perceptions of STEM fields. This paper presents the installation of a biomimetic robotic fish controlled by an iDevice application at an informal science learning exhibit. Visitors to the exhibit are offered a unique experience that spans engineering and science, in which they can steer the robotic fish, choosing from three modes of control. Visitor engagement is examined through the lens of the Selinda model of visitor learning, while their behavior is examined using an adapted model of Borun's framework for behaviors indicative of learning. The evaluation of the efficacy of the exhibit is assessed through a post-experience survey questionnaire, an analysis of the application usage, and a behavior coding study. Data collected on visitor interactions with the exhibit indicate that free-choice learners value the importance of engineering research, and prefer interactive modes. Further, behavior coding results support the ability of the robotic fish platform to capture the visitors' attention. Findings offer compelling evidence that the exhibit is both highly engaging to visitors and a suitable format for science inquiry.**

***Index Terms*—Biologically-inspired robots, education robotics, exhibit, free-choice learning, informal learning, mechanical engineering, mobile applications, engagement.**

## I. INTRODUCTION

INFORMAL science learning is a form of learning often described as highly unstructured and with limitless opportunities [1], [2]. Designed settings that cater to this form of learning include zoos, aquariums, and science museums [1]–[7]. Visitors can learn about the natural world through exhibits that often contain interactive and informational contents [2], [5], [6]. Visitors are free to choose the exhibits they interact with, the duration they spend at each exhibit, and the pace at which they engage with educational materials [2].

These circumstances lead to a diverse range of learning outcomes across visitors to a given exhibit [2], [4]. Recommendations from education professionals and exhibit designers [2] suggest that exhibits should have interactive components, to maximize potential learning outcomes. Interactivity is a crucial element to motivate visitors in the learning process [8], and to address previously held misconceptions about science [9].

Exhibits featuring robotic elements are gaining traction for both their interactivity [10]–[12] and novelty, especially to young visitors [13]. Robotics-based exhibits have been used to generate interest in space exploration [14], educate the public on concepts of human-robot interaction [15], and involve the general public in conscious environmental monitoring [16]. Robotics-based exhibits may afford a range of interactive elements, such as driving the robot, collecting sensory information, and enabling behavior-based interaction. Robotics has been shown to produce positive learning outcomes, from conveying knowledge to increasing interest in careers in science and engineering [17].

Within robotics-based activities, robotic fish have been shown to be highly effective as an educational tool for science, technology, engineering, and mathematics (STEM) fields [17]–[24]. Robotic fish activities have been developed to draw engineering analogies from fish propulsion [20] and physiology [23], promote friendly academic competition [19], excite students in engineering through design activities [17], [18], [21], and introduce state-of-the-art robotics research [24]–[26]. Most of the studies on robotic fish in informal science education focus on science festivals and fairs, which typically are high-traffic events that offer limited interaction with the exhibit [17], [22]. Although visitors interact with robotic fish only briefly in such exhibits, they have been found to be highly enjoyable [17], [22]. However, for learning, education professionals recommend that visitors' interactions should not be time-limited, to allow a personally comfortable learning pace and sufficient time to reflect on the experience [2].

This paper examines the potential of a robotic fish exhibit to expand understanding of visitor engagement and behavior in designed settings for informal science learning. To study visitor *engagement*, the duration and complexity of visitors'

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This paper has supplementary downloadable material available online at http://ieeexplore.ieee.org, provided by the authors. This consists of a PDF (575 KB) with screenshots of the post-experience questions and guide for behavior coding.

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

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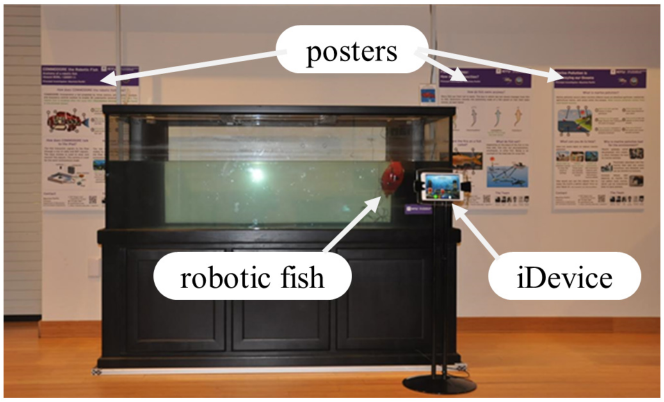


Fig. 1. Setup of the robotic fish at the Brooklyn Children's Museum, showing the posters, aquarium tank, iPad, and robotic fish.

interactions with the modes of the application are analyzed through the Selinda model of visitor learning [27]. To examine visitor *behavior*, behavior coding is used to gain a qualitative measure of the exhibit experience without interrupting the visitor experience [28], [29]. Borun's [28] framework for behaviors indicative of learning is used to classify observations made at the robotic fish exhibit. This study i) examines visitor engagement while using the application control mode through the perspectives of the Selinda model, ii) observes visitor behaviors at the novel robotic fish exhibit through Borun's framework for learning behaviors, and iii) quantifies knowledge learning outcomes through a traditional standard post-experience survey.

## II. Exhibit Experience

### A. Exhibit Description and Experience

The robotic fish exhibit, Fig. 1, was installed in New York City, NY, USA, at the River Project (http://www.riverprojectnyc.org/) from August 19, 2014 to September 22, 2014. Then, as part of the "More Than Meets the 'I' " exhibition, it was installed on the second floor of the Brooklyn Children's Museum (http://www.brooklynkids.org/) from October 9, 2014 to January 19, 2015, which is where the data for the internal application, post-experience survey, and behavior coding described below were gathered.

The exhibit features a variant of a robotic fish platform described in [30], whereby a robotic fish is remotely operated by an iDevice application. The exhibit includes a robotic fish, a 1,000 liter aquarium tank, a stand encasing an iDevice, and educational posters on the topics of robotics, fish physiology, and marine pollution. These topics are based on feedback from demonstrations of the platform at science fairs and festivals, where visitors indicated an interest in learning more about marine pollution [22].

The robotic fish uses an Arduino microcontroller to control three waterproof servomotors and actuate the tail to create the propulsion. The robotic fish is fabricated using 3D printed acrylonitrile butadiene styrene plastic parts, and uses a rubber silicone caudal fin. Two infrared sensors, mounted on the front of the robot, are used to detect obstacles. To establish the communication between the robotic fish and the iDevice application: i) user datagram protocol (UDP) is utilized between the iDevice and a router over Wi-Fi, ii) UDP is also implemented between the router and an Arduino Ethernet shield connected by an Ethernet cable, and iii) 434 MHz radio signals are used between an RFM22B radio transceiver on the robotic fish and a corresponding RFM22B radio shield.

The exhibit allows visitors to control the robotic fish with an iDevice application. Before interacting with the robot, visitors first see a screen where they must confirm their consent to collection of data that does not identify them personally. On a second screen, they then are asked to provide their demographic information of age and gender.

A brief tutorial demonstrates the application's three different control modes—manual, semi-autonomous, and autonomous—in which a visitor can, respectively: i) directly maneuver the robotic fish; ii) create a trajectory to guide the robotic fish through real-time visual feedback, or iii) allow the onboard infrared sensors to autonomously guide the robotic fish. The implementation of these modes is described in [30]. Visitors can switch between control modes throughout the interaction. After the interaction, they can opt to participate in a post-experience survey by pressing a 'Survey' button on the menu. After the survey, the application is reset back to a welcome screen.

All the visitors' actions, timestamps, demographic information, and post-experience survey answers are recorded in a SQLite Database located on the hard drive of the iDevice, and are periodically offloaded.

### B. Post-Experience Survey

The post-experience survey consists of five questions. As in [17], [21], and [22], some of the questions measure learning outcomes and others determine visitors' perception of science and engineering. These post-experience survey questions are optional and visitors can, at any time, elect to skip a question.

The first three questions deal with the knowledge of robotics and fish physiology that this exhibit seeks to impart or reinforce. The first question presents a game in which visitors are asked to match electronic components to their location on the robotic fish, specifically the microcontroller, sensors, motors, and the buoyancy controller. Visitors drag and drop the appropriate label over the location of the corresponding part. The second question asks the visitor to select which swimming mode the robotic fish uses: anguilliform, sub-carangiform, carangiform, or thunniform motion. The third question is another matching game, here on fish anatomy, featuring the head, caudal fin, dorsal fin, and pectoral fin. The fourth, multiple-choice, question evaluates visitors' interest in potential careers, asking them to select between: engineer, scientist, marine biologist, athlete, artist, and doctor. The fifth question asks the visitor's opinion of the importance of engineering research.

### C. Internal Application Data Collection

In addition to measuring learning outcomes, museum professionals are increasingly interested in how visitors create meaning from their experiences through the process of engagement [27]. They have suggested that, in order to foster science learning in the general public, exhibits should 'engage in more active modes of attending' [27]. This study uses the Selinda model of visitor learning to examine the extent of visitor engagement when offered varying levels of robot autonomy [27]. Specifically, the Selinda model identifies four aspects of visitor engagements: physical, emotional, intellectual, and social [27]. This study examines the physical and intellectual aspects, both of which were directly captured by the application. Physical engagements describe visitors' physical interactions with the exhibit, such as the time spent at the exhibit, or the objects (or modes) manipulated, while intellectual engagements describe the cognitive processes that take place, such as how visitors experiment at the exhibit [27].

As the visitor uses the iDevice, the application records the control mode used in real-time. This information was used to score the time spent by visitors in the exhibit, from the welcome screen to the post-experience survey. Physical engagement was characterized by the modes used and the total time spent at the exhibit.

However, as there is no guarantee as to the quality of the information reported by visitors and collected by the application, a few filter rules were created to provide an accurate understanding of the visitor application usage, by excluding cases in which visitors: i) used the application and left the application running; ii) touched the screen and left without much interaction; and iii) misrepresented their age. This set of filter rules was applied to all interactions. The navigational design of the application allowed the visitor to skip the control mode usage and the post-experience survey.

To quantify differences in time spent between the control modes, a one-way ANOVA test was used [31]. Since visitors could go from the demographic information screen straight to the survey, only 363 of the 438 valid interactions could be counted in the ANOVA test, that is, 363 interactions completed the control mode usage. To compare the total time use with the demonstrations at science fairs and festivals [22], a t-test for the difference between two means was applied [31].

Intellectual engagement was characterized by examining the user touches on the screen for each control mode. In addition to the temporal data by the application, the application also recorded the spatial data from user touches in the control modes. The spatial data was used to generate heat maps to examine visitor interaction at the exhibit, similar to [32] and [33].

### *D. Behavior Coding*

To better understand the potential for learning at the exhibit, visitor behavior is examined through an adaptation of Borun's framework [28]. Supporting the notion of using observations of behaviors as indicators of learning [4], [34], Borun's framework of behavior coding of families at designed settings implies that "if we see these behaviors, we can infer that learning is taking place" [4], [28]. Implementing Borun's framework at a variety of designed settings, such as science museums, aquariums, and zoo, has helped identify certain behaviors as being poor performance indicators of learning, for example, calling another visitor over to the exhibit, or pointing at the exhibit [28].

Behavior coding, a qualitative scoring measure, was used to gain an understanding within Borun's framework of visitor behaviors at the exhibit. The behavior coding tool developed for this study required a coder to score each occurrence of the behavior. Several specific behaviors were observed based on coding criteria established for informal science learning settings [28], [29]. For each occurrence, the behavior was scored into the appropriate section of the coding tool.

In the adaptation of Borun's framework used here, several behaviors were associated with one of three learning levels [28] that were constructs of the depth of learning achieved by the visitor [2], [28], [35]; a higher level indicates a deeper understanding of operations of the exhibit. Behaviors were classified according to Bloom's taxonomy [35], where the increasing depth of learning was separated into the broad categories of: remembering, understanding, applying, analyzing, evaluating, and creating. For example, the behavior of 'providing a verbal comment' was categorized at a lower learning level, as visitors often reiterated the information provided at the exhibit. On the other hand, 'demonstrating how to use the application to another visitor' was categorized at a higher learning level, since the visitors was applying their newly found understanding of the exhibit to help others.

The first learning level (the lowest level of learning) included asking another visitor a question, answering another visitor's question, making a verbal comment on the exhibit, and reading the text in the application aloud or silently. The second learning level comprised describing to another visitor how the application worked, and attempting to try the application. The third learning level consisted of demonstrating to another visitor how to use the application, verbally describing to another visitor how to control the robotic fish, and taking a picture of the exhibit. Additionally, the coding tool has a numerical measure to quantify whether visitors examined the posters on robotic fish anatomy, fish physiology, and marine pollution. In each case, if the visitor was observed standing in front of and reading the poster, the behavior of examining the poster was scored.

To account for non-learning activity, certain other behaviors associated with the logistics of the visitor group were scored. These included any instance when a visitor approached the exhibit, called another visitor over to the exhibit, pointed at the exhibit, or withdrew from the exhibit.

Further, a number of additional behaviors were scored, outside of logistics and learning behaviors. These included when a visitor expressed a liking or an aversion to the exhibit. If a visitor left the exhibit and returned later, this was scored as a repeated use, suggesting visitor interest. Also, the current group size of visitors at the exhibit was scored to examine the level of visitor traffic at the exhibit. For behaviors or notes outside of these expected ones, coders had a text box region in which to enter compelling observations.

The coders were two students (including the first author and an undergraduate student) from New York University Tandon. The undergraduate student was trained by the first author in a session following a detailed rubric to score the observed behaviors. To complete an observation, a coder pressed the 'Collect' button to record the behaviors, a timestamp, and the coder's initial to an internal database. The behavior coding study was conducted by two coders over 10.2 hours

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TABLE I
TOOLS, METRICS, AND ASSOCIATED CONSTRUCTS MEASURED IMPLICITLY OR EXPLICITY BY THE EXHIBIT FORMAT

| Tool | Metric/Question | Measured construct | Inferred implicitly/explicitly |
|---|---|---|---|
| Post experience survey | Robotic fish anatomy | Knowledge | Implicit |
| | Fish swimming | Knowledge | Implicit |
| | Fish anatomy | Knowledge | Implicit |
| | Career interest | STEM interest | Explicit |
| | Importance of stem | Perception of STEM | Explicit |
| Internal data collection | Time duration of usage | Physical engagement | Explicit |
| | Control mode usage | Physical engagement | Explicit |
| | Heat maps of interaction | Intellectual engagement | Implicit |
| Behavior coding | Learning level behaviors | Learning | Implicit |
| | Logistic behaviors | Non-learning | Implicit |
| | Other behaviors | Repeated use and unforeseen behaviors | Implicit |

distributed across five different days (Friday, November 7, 2014; Sunday, January 4, 2015; Wednesday, January 7, 2015; Friday, January 16, 2015; and Monday, January 19, 2015), during the exhibit's peak use period, between 11:00am and 4:00pm — 79% of all valid interactions occurred during those hours. The coders were positioned some five to ten meters away from the exhibit as to not interfere with the visitors' use of the exhibit. The metrics used in this study, the associated measured construct, and whether this is implicitly or explicitly inferred are categorized in Table I.

## III. RESULTS

After applying the filter rules, 438 valid uses of the application were identified at the exhibit. Of the visitors, 33.3% were male, 32.6% were female, and 34.1% did not answer. The self-reported average age of visitors was 13.9 with a standard deviation of 14.5. The median age was seven.

### A. Post-Experience Survey

Table II shows the percentages of visitors who answered correctly, incorrectly, or skipped the first three post-experience survey questions. For the first question in the post-experience survey on the matching of the robotic fish anatomy, only 13% of visitors who responded had all correct matches. For the second question on fish swimming patterns, 19% of visitors who responded answered correctly with carangiform swimming. For the third question on matching the fish anatomy, 38% of visitors who responded had all correct matches.

For the question on visitor interest in future careers, 7.3% indicated doctor, 13.7% indicated artist, 4.3% indicated athlete, 4.3% indicated engineer, 3.9% indicated marine biologist, 5.5% indicated scientist, and 61.0% skipped the question. STEM-related careers, when grouped in fields similar to [17] (scientist, engineer, or marine biologist), accounted for 35.1% of all the visitors who responded. The rest of the visitors chose careers related to arts (35.1%), medical practice (18.7%), and sports (11.1%).

For the question on visitor opinion on the importance of engineering research, 5.0% of visitor indicated that they

TABLE II
PERCENTAGES OF VISITOR RESPONSES TO THE FIRST THREE POST-EXPERIENCE SURVEY QUESTIONS

| Question | Incorrect | Correct | Skipped |
|---|---|---|---|
| 1 | 9.3 | 1.4 | 89.3 |
| 2 | 39.5 | 9.4 | 51.1 |
| 3 | 35.9 | 21.7 | 42.5 |

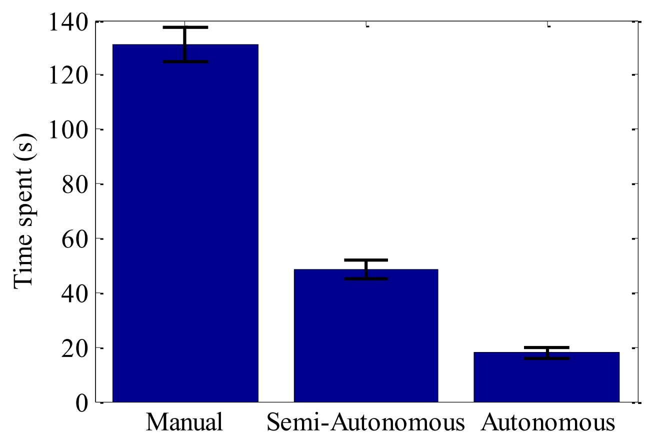


Fig. 2. Average time spent in the manual, semi-autonomous, and autonomous modes. Error bars indicate two standard errors of the time spent in the corresponding mode.

strongly disagreed, 4.1% disagreed, 5.5% were neutral, 13.2% agreed, 44.3% strongly agreed, and 27.9% skipped the question.

### B. Internal Application Usage

Visitors spent on average 131 seconds in the manual mode with a standard error of 6.7 seconds; 49 seconds in the semi-autonomous mode with a standard error of 3.9 seconds; and 18 seconds in the autonomous mode with a standard error of 2.2 seconds, see Fig. 2.

The difference in time spent between the control modes was found to be statistically significant. ANOVA rejected the null

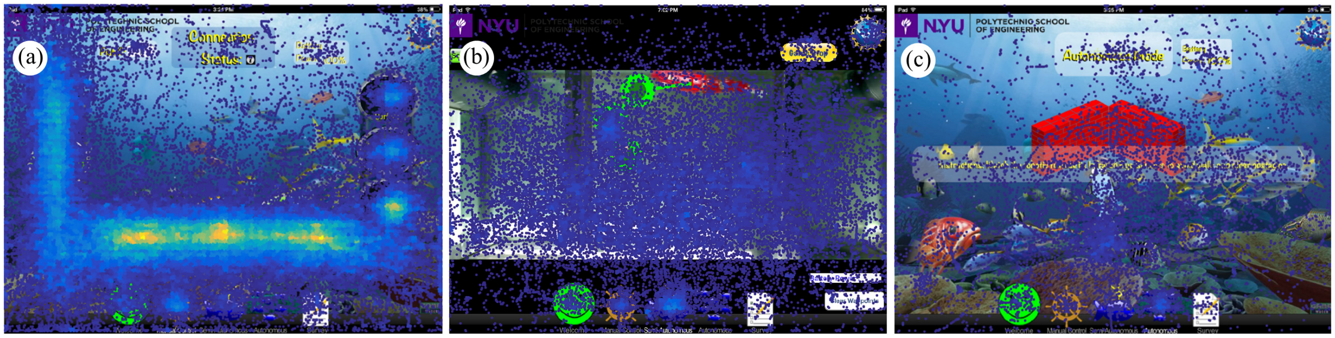


Fig. 3. Heat map of user touches in the (a) manual, (b) semi-autonomous, and (c) autonomous modes.

hypothesis that the variances in time usage between the control modes were equal ($F_{2,1089} = 160$, $p < .01$) [31]. At the museum, for the percentage of time spent in the control modes, visitors spent 66.2% of their time in the manual mode, 24.7% in the semi-autonomous mode, and 9.1% in the autonomous mode. During science festivals, visitors spent 53.5% of the time in the manual mode, 43.4% in the semi-autonomous mode, and 3.1% in the autonomous mode [30].

The t-test ($t = 4.10$, $p < .01$) for the total time spent in the control modes also indicated that, with uninterrupted use, visitors spent more time at the exhibit installments, 198 seconds, in comparison to demonstrations at science festivals, 159 seconds [22].

Fig. 3 shows heat maps generated from data of all users' touch on the screen, overlaid on the control modes. The highest concentrations of the user touches were on the sliders in the manual mode, on the real-time video of the water tank in the semi-autonomous mode, and on the animated fish in the autonomous mode.

### C. Behavior Coding

The behavior coding indicated that there were 50 instances where visitors observed the robotic fish poster, 19 where they observed the fish physiology poster, and none where they observed the marine pollution poster. There were 204 instances of logistic behaviors. There were 125 instances where a visitor approached the exhibit, 12 where a visitor called another visitor over to the exhibit, seven where a visitor pointed at the exhibit, and 60 where a visitor withdrew from the exhibit.

In total, there were 120 instances of learning behaviors. Specifically, there were 46 cases of the first learning level with the breakdown for asking a question to another visitor, answering the question of a visitor, providing a verbal comment of the exhibit, and reading the text in the application aloud or silently being 15, 5, 24, and 2, respectively. There were 64 occurrences of the second learning level with 14 instances of a visitor describing how the application works to another visitor and 50 of a visitor attempting to try the application. Finally, there were 10 instances of the third learning level behaviors with four cases of demonstrating how to use the application to another visitor, four of describing the controls to a peer, and two of taking a picture of the exhibit.

Of the recorded observations, there were 11 cases of visitors expressing a liking to the exhibit, none of a disliking, and 18 of repeated use. The instances where visitors responded with positive expressions indicated that the exhibit was able to elicit enjoyment, as expected from previous demonstrations [22]. The group size ranged between one and ten with a median of two, which indicated that usually there were no large crowds, unlike the atmosphere of science festivals [22].

## IV. Discussion

An interactive robotic fish exhibit was deployed at designed settings, under the premise that the platform would generate positive learning experiences for visitors, based on the success of robotic fish platforms at science fairs and festivals [17], [22]. A combination of quantitative and qualitative measures was collected from the post-experience survey, application usage, and behavior coding to demonstrate the potential of the intersection between robotics and science in informal science education. Based on [17], [21], and [22], it was hypothesized that observations would show implicit learning, positive visitor attitudes towards STEM careers and research, increased time spent at the exhibit than in events in festivals or fairs (especially in interactive modes), and occurrences of behaviors associated with learning. The experiments generally supported all these hypotheses, although learning outcomes were weaker than initially anticipated.

### A. Post-Experience Survey

The questions on the post-experience survey provide a quantitative self-reported measure of visitor knowledge, interest in career fields, and opinions of engineering research. The higher scores observed for the matching game for the fish anatomy over the robotic fish anatomy may possibly be explained by the visitors' having more prior common knowledge about animals and the natural world than of robotics, electronics, and mechatronics.

Although the first three survey questions indicated limited visitor proficiency in robotics and fish physiology immediately after the seeing exhibit, the possibility of some learning of the topics cannot be dismissed. Other studies conducted in designed settings [2] support the possibility that learning is only partially evaluated through instantaneous measures, which do not account for long-term learning [36]. In fact, visitors may reflect on the experience well after the visit, or build on this knowledge with repeated exposure to informal science learning settings through a genuine interest developed over time [5], [37], [38]. However, the lack of a pre-experience survey does not allow for a direct assessment of knowledge gain or learning. Future studies should seek to include pre-experience assessment tools to elucidate the effect of the exhibit on learning. Care should be taken that the inclusion of a pre-survey does not impinge on the informal learning experience at the exhibit.

For the fourth question, although responses for the top three chosen career categories were similar to [17], we register that a majority of visitors chose to skip this question. The young age of visitors might have been a factor in the low response to career selection, in that future careers are more likely to be thought of by older visitors, in the middle school or high school range. Alternatively, visitors may not have been able to make the connection between the purpose of the exhibit (to promote interest in STEM) and career awareness, as opposed to science fairs and festivals where staff members (part of the research team who developed the robotic fish) are available to describe the engineering or science aspect of the project [22].

Findings for the fifth question resonate with previous work indicating that, after a robotic fish-based activity, visitors had a positive attitude towards engineering [17], [21], [30].

### B. Internal Application Usage

Although both active and passive interactions count as physical engagements in the Selinda model [27], the application usage of visitors indicates that they used the manual mode the longest, followed by the semi-autonomous mode and then autonomous mode. This finding is in line with previous research for the platform at fairs and festivals, where time spent was largely budgeted toward interactive modes [30]. This also supports recommendations from [8] and [39], where education professionals have proposed the use of interactive features over passive approaches, such as those associated with the autonomous mode. However, compared to demonstrations in science festivals, there was a decrease in the percentage of time spent in the semi-autonomous mode.

An explanation for this may be that, in contrast to science festivals where staff members promptly provided helpful explanation about the application, in this new setting visitors were on their own, and may have not fully understood the controls for the semi-autonomous mode. Alternatively, the exhibit design itself may have been a factor for the decrease in the time spent in the semi-autonomous mode, if the tutorial was not clear to visitors. This finding suggests that having staff members or interpreters for the exhibit may be desirable for museum settings, as well as science festivals. In line with the predictions, visitors spent overall more time with the exhibit at designed settings than at science festivals.

The time spent with this robotic fish platform—a ‘desirable’ physical engagement trait in the Selinda model [27]—was comparable to similar exhibits, where interactions were on average 82 to 224 seconds per exhibit [14], [40]. For the intellectual engagements, the heat maps indicated that the visitors were experimenting with the control modes as intended. For example, in the manual mode, the high concentration of visitor touches at the slider possibly indicate that they were exploring the effects of changing the vertical slider on fish speed. Similarly, in the semi-autonomous mode, the scatter of the visitor touches suggest that visitors explored a range of trajectories spanning the entire viewing area. Alternatively, in the autonomous mode, visitors may have felt the urge to tap on the animated fish to elicit a reaction from the robotic fish.

### C. Behavior Coding

To further elucidate the visitor behavior and interactions at the exhibit, behavior coding was used to gather information that is often not accessible through post-experience surveys. The behavior coding scores associated with the posters indicated that visitors did observe the robotic fish and the fish physiology poster, while they may have overlooked the marine pollution poster. Thus, it is tenable to hypothesize that visitors gained some interest in robotics through the exhibit format. Although there were more instances of visitors observing the robotic fish poster than the fish physiology poster, they scored better on fish physiology questions, probably because they had more prior knowledge of the natural world than of robotics.

Additionally, the posters, by design, may have not fit the target audience of the science venue, as the disengagement with the marine pollution poster contrasts with expectations of visitor interest indicated at demonstrations at science festivals [22]. To increase the opportunity that content knowledge be effectively captured by the audience through the posters, their message may be refined based on recommendations for exhibit texts and labels [41], such as satisfying the visitors’ curiosity, establishing an appropriate conversational tone, and ensuring text readability and conciseness. For example, the poster text label could read ‘How do engineers build a robotic fish?’ rather than the current ‘Anatomy of a robotic fish’.

The logistic behavior indicated that there was activity at the exhibit, but this did not necessarily transfer into learning, as the number of behavior instances decreased with higher learning levels. The finding on the distribution of instances of learning level behaviors is similar to [28], where the majority of families in informal science learning settings were categorized as having reached only moderate learning (Level 1 and 2). In general, these findings on learning behaviors indicated that there was a high occurrence of visitors providing a verbal comment of the exhibit and attempting to try the application, consistent with behaviors at exhibits at designed settings [28].

The behavior coding tool provided several opportunities to capture unanticipated outcomes through a text box and allowed coders to confirm instances of repeated use. As the post-experience survey and internal application data collection did not gather personally identifiable information, instances of repeated use can only be confirmed through behavior coding. Behavior coding confirmed that there were 18 instances of repeated use. Another common behavior was the event of parent-child conversation at the exhibit. This interaction was often in the form of either the parent, having read the poster, guiding the child on the application, or the child figuring out the application and calling a parent over to show his/her findings. The third commonly observed behavior was of a child asking if the robotic fish was alive. In one case, there was


Fig. 4. (a) A young visitor begins controlling the fish without instructions and (b) moments later goes up to pet the fish before going back to the screen to control the robotic fish.

a young visitor, in the middle of using the application, who went over to 'pet' the fish, see Fig. 4.

These simple, yet unanticipated, behaviors offer preliminary evidence toward future studies on the potential use of the robotic fish activity to explore learning in the context of repeated uses, on the impact of family interaction, and on children's perception of the natural world (or ability to distinguish between robots and living specimens). For example, an investigation through the lens of the 'uncanny valley' to examine children's perception of the natural world may potentially utilize robotic fish prototypes of varying degrees of realism. In addition to the information derived from the behavior coding, the authors believe that the application-based tool approach presents a new paradigm for behavior coding by enabling coders with an effective method to collect data quickly, compared to pencil and paper techniques [28], [29] and may prove highly valuable in exploring informal learning in museum settings.

### *D. Limitations*

While this study provides an informative look at how visitors interacted with the exhibit, there are some limitations in terms of audience and presentation. First, the exhibit was initially intended for the New York Aquarium where drawing the connection between biology and engineering through the use of the robotic fish can be relatable for visitors. However, the damage done by Hurricane Sandy to the New York Aquarium necessitated the relocation of the exhibit installment. This change may have potentially weakened the learning experience, in contrast to similar activities [18], [21] which were conducted immediately after viewing live fish.

Future installations of the exhibit will examine post-experience survey responses for a venue with an older visitor audience, as the younger ages are already captured by the Brooklyn Children's Museum. Alternatively, survey questions could be improved to account for age following the guidelines suggested in [42], including using short questions and simple language, reiterating that there are no right or wrong answers, and developing several different versions for different age and ability groups.

In retrospect, the fourth question on interest in future careers is not relevant for adults. In the future, this survey question could be filtered based on the reported age or eliminated altogether. Further, in hindsight, the career information could be elaborated to provide context for the exhibit. For example, brief descriptions of the careers may be added to the career images for engineer ('We design and make stuff, and we built this robotic fish!'), scientist ('We learn about the natural world and we can test the speed of the fish!'), marine biologist ('We learn about the animals living underwater and we also learn about how they move!'), athlete ('We play sports like volleyball and basketball!'), artist ('We color and make paintings!'), and doctor ('We practice medicine and help people get better!'). For a quantitative measure of the added value of the installation on visitors' interest in STEM careers, a pre-and post-experience survey should be administered on the application at the exhibit. Alternatively, control groups could be used to assess the impact of the robotics-based exhibit, similar to the approach presented in [21] to evaluate the effectiveness of a robotics-based after school program for middle school students.

Although the exhibit did engage visitors longer in an informal science learning exhibit, the overall setup was not exactly comparable to the presentation at the science fairs and festivals. Specifically, at science fairs and festivals there were staff members and no posters, while at the exhibit there were posters and no staff members. Although posters may be a common format for scientific presentations, the findings from the behavioral coding suggest that this medium may be not be as effective in an interactive exhibit.

## V. Conclusion

The robotic fish exhibit at informal science learning venues has shown to be effective in engaging visitors. Further, internal data collection and behavior coding suggested that visitors often elected to spend time in the interactive mode and that there was evidence of repeated use. In the uninterrupted setting, although evidence for learning was not clear, visitors agreed that engineering research is important. Future installations of the exhibit will explore alternative control devices to drive the fish, and emphasize the learning content on marine pollution and robotics through other media. For instance, take-home pamphlets or a video loop presenting the engineering process of the robotic fish will be installed nearby the exhibit, possibly as an alternative to posters, to increase visitor connection to the engineering aspects of the exhibit.

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## Compliance With Ethical Standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The data collection for this study is done in accordance to the regulations of the University Committee on Activities Involving Human Subjects of New York University (IRB#14-10152).

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