Microrobotics Takes Flight (RoboBees)

Summative Evaluation Report

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EXECUTIVE SUMMARY

In 2013 and 2014, the Museum of Science (MOS) partnered with Dr. Rob Wood's lab at Harvard University's School of Engineering and Applied Sciences (SEAS) to create an exhibition about Wood's Robotic Bees (RoboBees) project. The *Microrobotics Takes Flight* exhibition (referred to in the original grant as the *RoboBees* exhibition) consists of three interactive components and an introductory section. The three interactive components are modeled on the three different engineering teams working on the RoboBees project: the Brain, the Body, and the Colony teams. The purpose of the evaluation was primarily to understand the extent to which visitors understood the exhibition's main messages or goals, as well as to gain an understanding of how visitors interact with the exhibition when not cued to do so. Therefore, the following questions guided this summative evaluation:

1. How do visitors interact with the *Microrobotics Takes Flight* exhibition?
2. How does visiting the *Microrobotics Takes Flight* exhibition impact visitor understanding of the associated main messages and learning goals?

In addition, to inform future exhibits and programmatic efforts in this area, the following supplementary question was explored as a part of the summative evaluation:

3. How does visiting the *Microrobotics Takes Flight* exhibition impact visitors' interest in or knowledge about engineering?

Data collection involved two sample groups: visitor groups who used the *Microrobotics Takes Flight* exhibition for at least 30 seconds (the "Post" group) and, as a comparison group, visitor groups near the *Microrobotics Takes Flight* exhibition and general engineering exhibition area but who had not used the *Microrobotics Takes Flight* exhibition (the "Pre" group). These visitor groups were *not* cued by MOS staff. Data were collected through observations (Post only), interviews (Pre and Post), and surveys (Pre and Post). Evaluation data were collected from 81 groups comprised of 182 visitors during multiple data collection sessions over a two month period in June and July 2014.

Findings suggest that overall, the *Microrobotics Takes Flight* exhibition achieved most, but not all, of its goals. The exhibition was successful in getting visitors to recognize the challenges of creating tiny flying robots like RoboBees, understanding the possible uses of the RoboBee, and recognizing that the RoboBees project is not finished. In addition, the exhibition was successful in helping visitors to understand that what they were doing is something like the engineering process. The exhibition was less successful in getting visitors to understand how the team broke down the problem by creating specialized teams. However, in general, the exhibition seems to clearly communicate the broader message about the process of research and engineering as opposed to the final product only.

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I. INTRODUCTION

1. EXHIBITION DESCRIPTION

In 2013 and 2014, the Museum of Science (MOS) partnered with Dr. Rob Wood's lab at Harvard University's School of Engineering and Applied Sciences (SEAS) to create an exhibition about Wood's Robotic Bees (RoboBees) project. Dr. Wood included development of the exhibition in the Broader Impact section of the National Science Foundation (NSF) grant that provided the funding for the RoboBees project. The exhibition was installed at MOS on May 28, 2014. This summative evaluation focuses on the impacts of the exhibition on the public. Previous evaluation of the exhibition that was conducted was formative, focusing on development of the individual exhibition components.

The *Microrobotics Takes Flight* exhibition (referred to in the original grant as the *RoboBees* exhibition) consists of three interactive components and an introductory section. The three interactive components are modeled on the three different engineering teams working on the RoboBees project: the Brain, the Body, and the Colony teams. The exhibition is situated near thematically similar exhibitions about engineering and locally developed, cutting-edge technologies. The full exhibition is pictured below (Figure 1). Body Lab is not visible, but is situated directly behind Colony Lab, back-to-back.

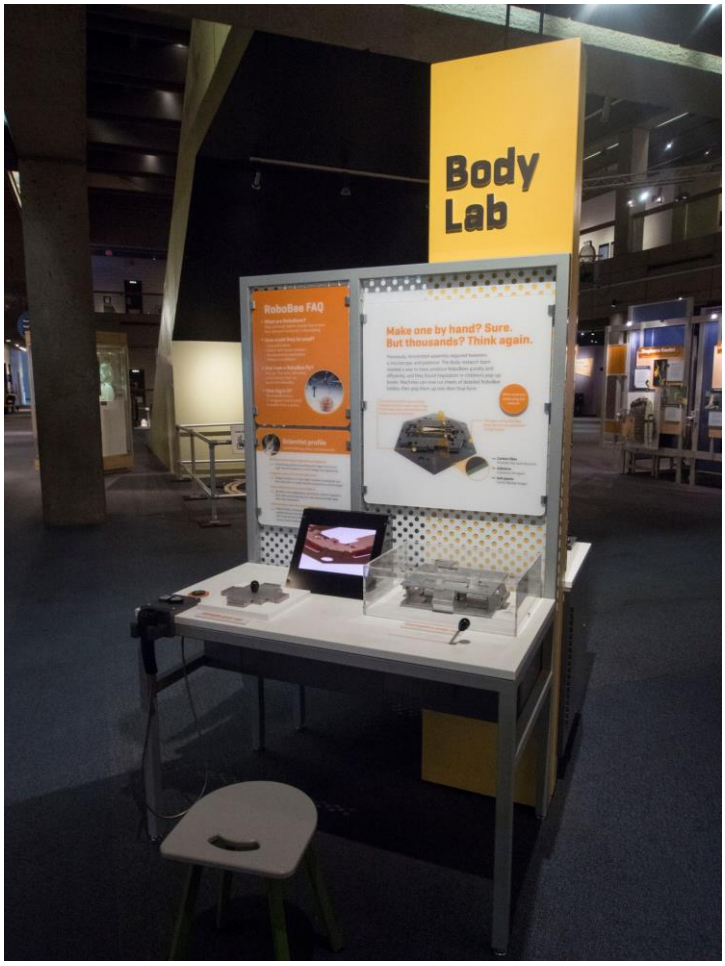
FIGURE 1. Photo of the Full Exhibition.

Pictured below is the Introductory Section to the *Microrobotics Takes Flight* exhibition, where visitors can learn about the project, watch videos of the RoboBees flying, see a real RoboBee, and watch interviews with engineers working on the project (Figure 2).

FIGURE 2. Photo of the Introductory Section.

At the Body Lab, visitors can learn about how the Body team develops innovative methods for mass production of the RoboBees. Visitors lift two example pop-ups (not RoboBee-shaped) to see the different kinds of hinges employed in the pop-up construction and watch a short video of a RoboBee being made with the pop-up construction method (Figure 3).

FIGURE 3. Photo of the Body Lab.



At the Brain Lab, visitors can experiment with different sensor and battery combinations to try to get the RoboBee to perform four basic functions. Visitors place different sensors and batteries into an enlarged model of the RoboBee and watch four different progress bars, as well as weight and battery scales, which instantly give feedback about the RoboBee they are designing. When they find a successful balanced combination, the large bee's wings light up (Figure 4).

FIGURE 4. Photo of the Brain Lab.

At the Colony Lab, visitors play a game where they control a group of 1,000 RoboBees and try to pollinate 8 flowers clusters. Visitors must choose how to efficiently send their RoboBees to explore the environment and then pollinate the flower clusters they find. At the end of the game, they get a score and are prompted to try again to improve their efficiency (Figure 5).

FIGURE 5. Photo of the Colony Lab.

The main messages for this exhibition are the following:

Primary messages:

- The RoboBees team is developing innovative methods to solve research challenges.
- The project leads broke down the problem by creating specialist research teams for development of the body, brain, and colony.

Secondary messages:

- The RoboBees team includes a diverse group of people encompassing a range of specialties and expertise.
- RoboBee technology could be used for many different applications in the future, but the project is not yet finished.

The goals for this exhibition are the following:

- Visitors will learn about challenges researchers face when developing small robots.
- Visitors will learn how the RoboBee team approached the challenge of building a tiny flying robot by breaking into specialized teams.

- Visitors will understand that the RoboBee project is not yet finished.
- Visitors will interact with physical and digital representations of the RoboBee.
- Visitors will explore interactives that represent actual challenges researchers face while working on the Colony, Brain, and Body teams.

In addition, each exhibition component had goals that evaluators kept in mind during the course of the evaluation:

"Colony Lab" Goals

- Visitors will execute a colony goal, while working with limited resources.
- Visitors will use feedback from the environment to inform their decisions.

"Brain Lab" Goals

- Visitors will explore a combination of power sources and sensor capabilities.
- Visitors will understand the tradeoffs involved in the Brain system.

"Body Lab" Goals

- Visitors will explore pop-ups with increased complexity.
- Visitors will understand the need for and process of RoboBee pop-up construction.

2. ABOUT THE EVALUATION

The purpose of the evaluation was primarily to understand the extent to which visitors understood the exhibition's main messages or goals, as well as to gain an understanding of how visitors interact with the exhibition when not cued to do so. Therefore, the following questions guided this summative evaluation:

1. How do visitors interact with the *Microrobotics Takes Flight* exhibition?
2. How does visiting the *Microrobotics Takes Flight* exhibition impact visitor understanding of the associated main messages and learning goals?

In addition, to inform future exhibits and programmatic efforts in this area, the following supplementary question was explored as a part of the summative evaluation:

3. How does visiting the *Microrobotics Takes Flight* exhibition impact visitors' interest in or knowledge about engineering?

II. METHODS

1. SAMPLING PROCEDURE

Data collection involved two sample groups: visitor groups who used the *Microrobotics Takes Flight* exhibition for at least 30 seconds (the "Post" group) and, as a comparison group, visitor groups near the exhibition and general engineering exhibition area but who had not used the *Microrobotics Takes Flight* exhibition (the "Pre" group). These visitor groups were *not* cued by MOS staff. The target age range for the evaluation was matched to the target age range of the exhibition, which was visitors ages 8 and up. Evaluation data were collected from 182 visitors during multiple data collection sessions over a two month period in June and July 2014.

For the Pre group, data collectors used continuous random sampling to recruit groups near the *Microrobotics Takes Flight* exhibition. Any visitor group who neared the exhibition and appeared to look at it for at least 2 seconds was approached. If the visitor group agreed to participate in the evaluation and confirmed that they had not seen the *Microrobotics Takes Flight* exhibition, the data collector conducted a short interview. The data collector also had one member of the visitor group complete a short survey relating to the exhibition goals and evaluation questions. The data collector offered the survey to the whole group and let them decide who would fill it out.

For the Post group, the data collector used continuous random sampling and began observing any visitor group that interacted with the *Microrobotics Takes Flight* exhibition for more than 30 seconds, as measured on a stopwatch. For groups that met this threshold, data collectors tracked which components of the exhibition were used and how thoroughly each group used them. If the group split up and the data collector could not follow all of their actions, data collectors chose the visitor physically closest to them to be the focus visitor and tracked that visitor. When the group appeared to leave the exhibition, the data collector approached the group to ask if they would be willing to participate in the evaluation. If they agreed, the data collector asked the group several interview questions, including some questions about perceived main messages from the exhibition and what, if anything, the group learned from the exhibition. One member of the visitor group also completed the same short survey as the Pre visitors, related to exhibition goals and evaluation questions. If the group had a focus subject, the focus subject filled out the survey. Otherwise, the data collector offered the survey to the whole group and let them decide who would fill it out. The Post group survey also included retrospective pre/post Likert scale questions, where the visitor rated their knowledge and interest on certain dimensions by marking the choice they would have made before visiting the exhibition as well as their current rating.

2. DATA COLLECTION INSTRUMENTS

Data were gathered from study participants by tracking visitors as they used the exhibition, interviewing visitors, and surveying visitors. Copies of the data collection instruments can be found in Appendices A-C.

2.1 Tracking

When a group composed of members all aged 8 or older approached the exhibition and interacted with it for 30 seconds, data collectors began recording which exhibition components they used and which elements of those components they interacted with. Tracking data involved whether visitors used audio labels, watched videos, tried sensors or batteries at Brain Lab, completed the Colony Lab game, and so on. So as not to lose data, data collectors attempted to mentally keep track of and then record what the group was interacting with during the initial 30 seconds of their interaction. Data collectors also attempted to observe the entire group where possible. If this was not possible, due to group size or the components that the group used, data collectors selected a focus subject, in this case, the visitor who happened to be physically closest to the data collector. Tracking data were collected for the Post group only, and data were collected from 41 visitors. A copy of the instrument can be found in Appendix A.

2.2 Visitor interview

To understand what Post group visitors got from their visit to the *Microrobotics Takes Flight* exhibition, data collectors conducted an exit interview with groups who had been tracked. Visitors were asked what was most interesting about the exhibit, what they thought the Museum was trying to have them learn, what (if anything) they learned from the exhibit, what (if anything) they did in the exhibition that was like what an engineer does, the process researchers might go through when making tiny flying robots, and what a RoboBee could be used for. They were also asked to explain their answer to one survey item. A total of 41 visitor groups participated in the interview. A copy of the instrument can be found in Appendix B.

Pre group visitors were asked one question from this interview in order to compare their responses to the Post group visitor responses. These visitors were asked about the process researchers might go through when making tiny flying robots. A total of 40 visitor groups participated in the interview. A copy of the instrument can be found in Appendix B.

2.3 Visitor survey

After the interview, each Post group was given a short survey and given the opportunity to choose who wanted to fill it out. If the group had a focus subject, the focus subject was given the survey. The survey asked whether the visitor had heard of the RoboBees project before today and to what degree they agreed with a statement that the project was finished, followed by a series of Likert scale agreement items about knowledge and interest in engineering and another about the exhibit's main messages. The Post group was asked to rate the Likert scale items retrospectively, by marking what they would have said before visiting the exhibition and what their rating was just after seeing the exhibit. After they finished the survey, they were asked to explain their answer for the question about whether the RoboBees project was finished. Forty visitors filled out surveys. A copy of the instrument can be found in Appendix C.

The Pre group was given the same survey, minus the question about whether the project was finished, and with no retrospective ratings. Pre groups were also given the opportunity to choose which group member wanted to fill it out. Forty visitors filled out surveys. A copy of the instrument can be found in Appendix C.

3. DEMOGRAPHICS OF PARTICIPANTS

The sample for the summative evaluation included 40 Pre groups and 41 Post groups. The two sampled groups were very similar to each other, but there were some small differences that should be kept in mind when contextualizing the evaluation findings.

3.1 Pre Group Demographic Information

The Pre group was composed of about two-thirds adult only groups and about one-third adult and child groups and had close to a fifty-fifty split of males and females (see Figures 6 and 7). When asked if they had a low, medium, or high background in science or engineering, the most common answer was "Low," while the median answer was "Medium" (see Figure 8). In addition, one visitor group indicated that they had heard of the RoboBees project before.

FIGURE 6. Pre Group, Sex and Group Types (N=40).

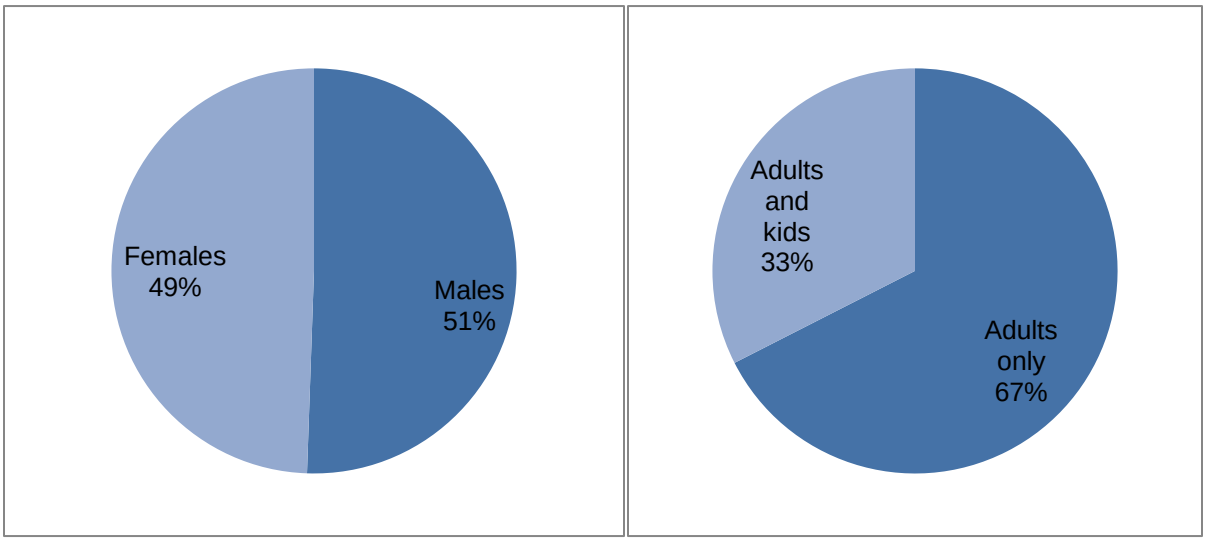


FIGURE 7. Pre Group: Sex Breakdown Among Adults and Kids (N=40).

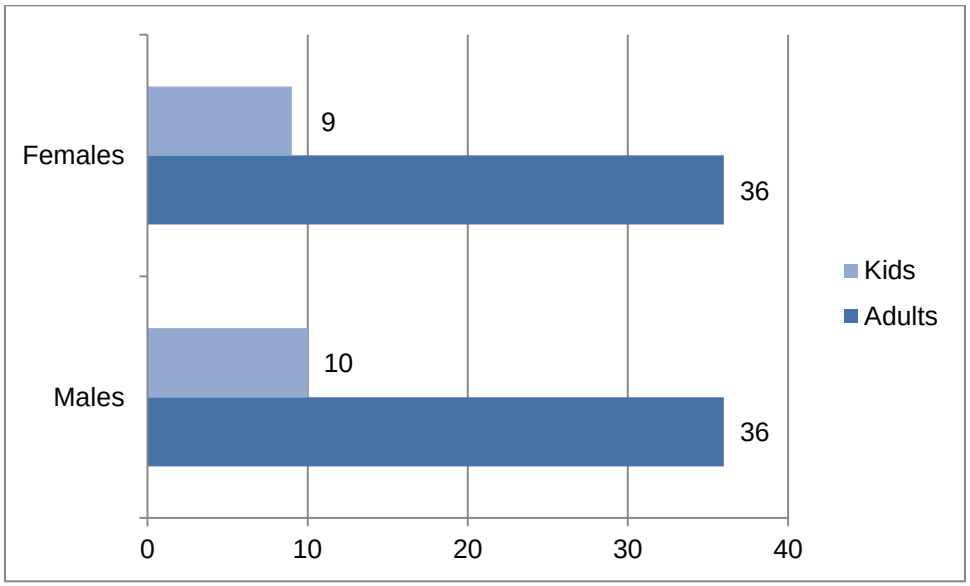
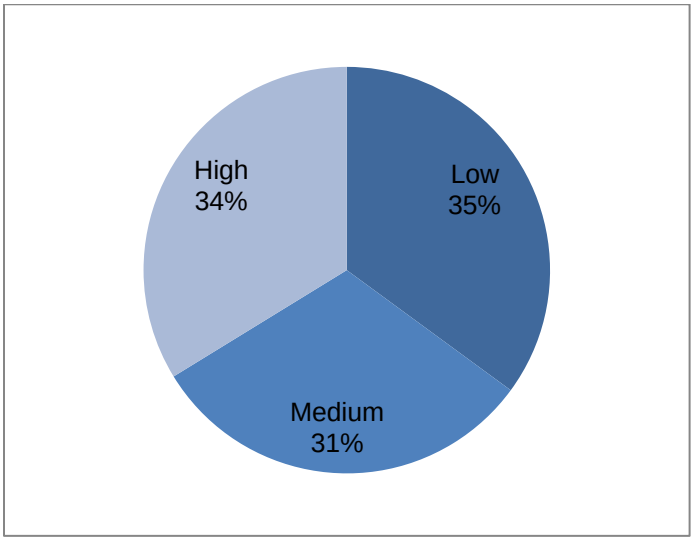


FIGURE 8. Pre Group: Visitor Rating of Their Background in Science or Engineering (n=77).



Visitors who said they had a "medium" or "high" background in science were asked what that background was. A Pre visitor's example of "Medium" background was, "I took engineering and design classes in high school. [I've] always been interested in science." An example of "High" background was, "I have a Master's in ecology and evolutionary biology."

3.2 Post Group Demographic Information

There were some slight differences between the Pre and Post groups, although they were not statistically significant. By percentage, the Post group included more adult and child groups as well as more males, mostly due to there being more male children than female children in the Post group (see Figures 9 and 10). By percentage, the Post group also had more visitors rating themselves as having a high background and science and engineering and fewer rating themselves as having a low background (see Figure 11). The median answer was medium background, and the most common (mode) answer was high. Similar to the Pre group, only 3 visitor groups in the Post group said they had heard of the RoboBees project before they visited the exhibition.

FIGURE 9. Post Group: Sex and Group Types (N=41).

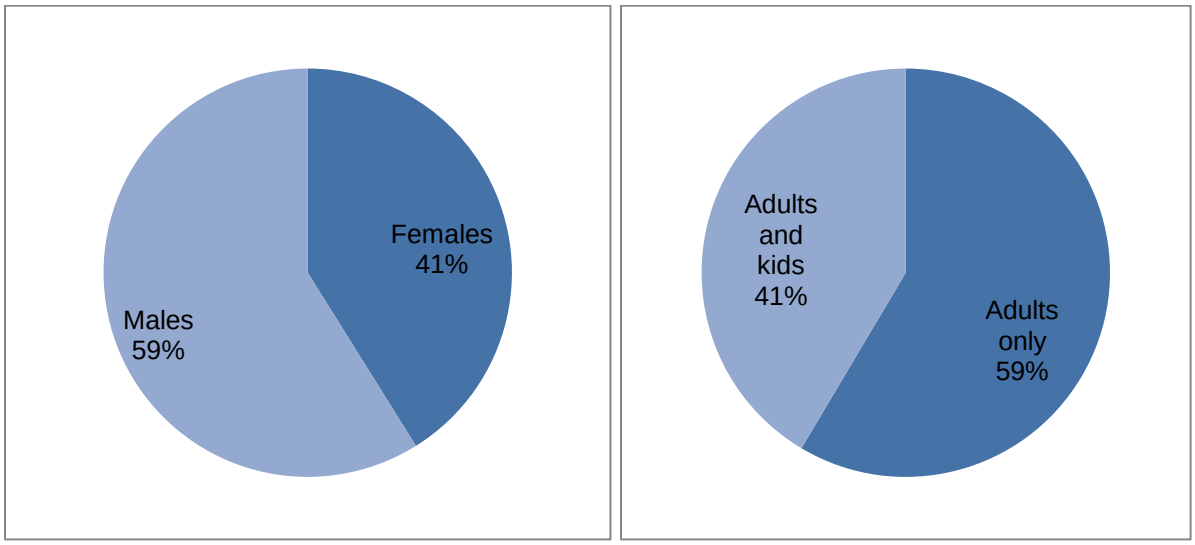


FIGURE 10. Pre Group: Sex Breakdown Among Adults and Kids (N=41).

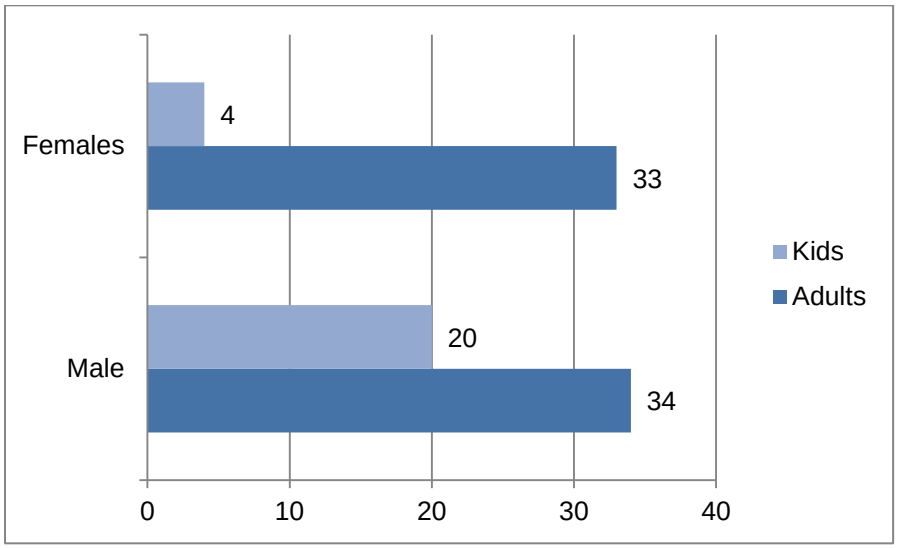
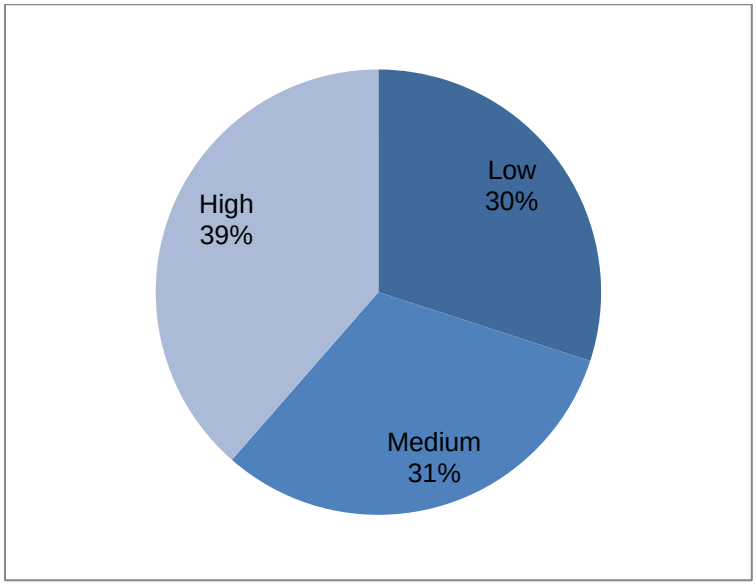


FIGURE 11. Post Group: Visitor Rating of Their Background in Science or Engineering (n=70).



Visitors who said they had a "medium" or "high" background in science were asked what that background was. A Pre visitor's example of "Medium" background was, "We like to listen to news and read science and tech articles. We're members. We keep current and try to stay on top of science and tech things." An example of "High" background was, "I'm an astrophysicist."

III. RESULTS AND DISCUSSION

This section of the report describes findings from the summative evaluation of the *Microrobotics Takes Flight* exhibition. Findings are organized based on the three evaluation questions, which were the following:

1. How do visitors interact with the *Microrobotics Takes Flight* exhibition?
2. How does visiting the *Microrobotics Takes Flight* exhibition impact visitor understanding of the associated main messages and learning goals?
3. How does visiting the *Microrobotics Takes Flight* exhibition impact visitors' interest in or knowledge about engineering?

Findings are organized in three sections. Examples of visitor quotes from interviews are included in each section.

1. HOW DO VISITORS INTERACT WITH THE *MICROROBOTICS TAKES FLIGHT* EXHIBITION?

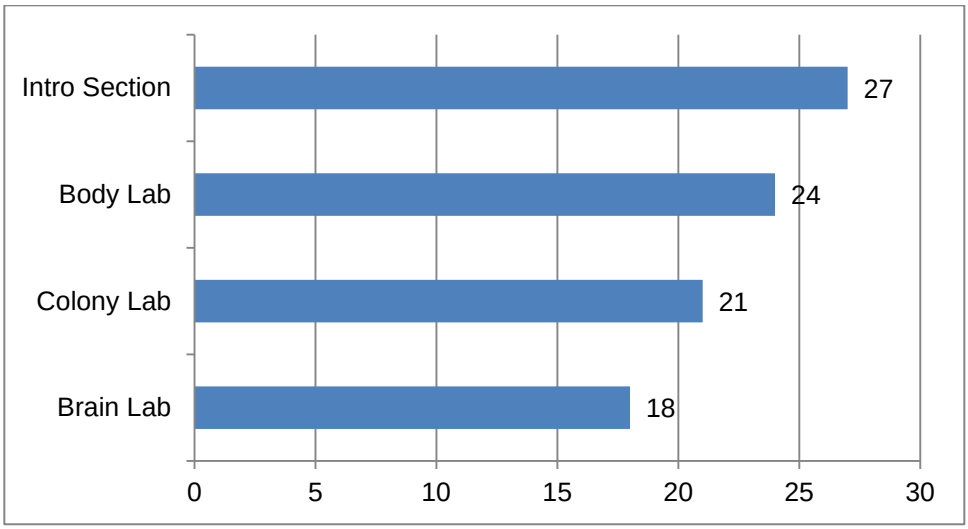
In order to understand how visitors use the *Microrobotics Takes Flight* exhibition, evaluators collected observational tracking data on visitors' usage of the exhibition. The sections below provide findings that explain more about how visitors tend to use the exhibition. The findings are the following:

1.1 Visitors to the *Microrobotics Takes Flight* exhibition tended to use the Intro Section and one of the interactive components, most often Body Lab.
1.2 The core interactive components were generally used thoroughly by the visitors who interacted with them.

1.1 Visitors to the Microrobotics Takes Flight exhibition tended to use the Intro Section and one of the interactive components, most often Body Lab.

Tracking data were collected for the 41 Post groups as they used the exhibition. While observing these groups, data collectors observed which components the groups visited and what they did at each component. In four cases, the groups split up such that the data collector could not observe the whole group's actions at the same time. In those cases, the data collector chose a focus visitor to track. In all other cases, the group either stayed together or stayed close enough that the data collector could observe all members. Body Lab, Colony Lab, and Brain Lab are considered the "interactive components," since they involve an activity for visitors that mirrors a challenge faced by the RoboBees team. Figure 12 below displays which components groups visited.

FIGURE 12. Number of Groups Visiting Exhibition Components (N=41).



Twenty-seven groups visited the Intro Section, and the Body Lab was the most visited of the core interactive components. Visitors tended to use the Intro Section most often, which contains a great deal of basic information about the RoboBees project, including a real RoboBee that visitors can see. Since the vast majority of visitor groups indicated that they had not heard of the RoboBees project before visiting the exhibition, it is likely that visitors were especially interested in this basic information. Visitors also tended to use the Body Lab the most of the three core interactive components. One possible reason for this is that the Body Lab is situated facing outward on a busy walkway and is the closest exhibition component to the popular *Theater of Electricity* and close to a top-down view of the *Dinosaurs* exhibit, another favorite at the Museum of Science.

FIGURE 13. Combinations of Exhibition Components Visitors Tended to Use (N=41).

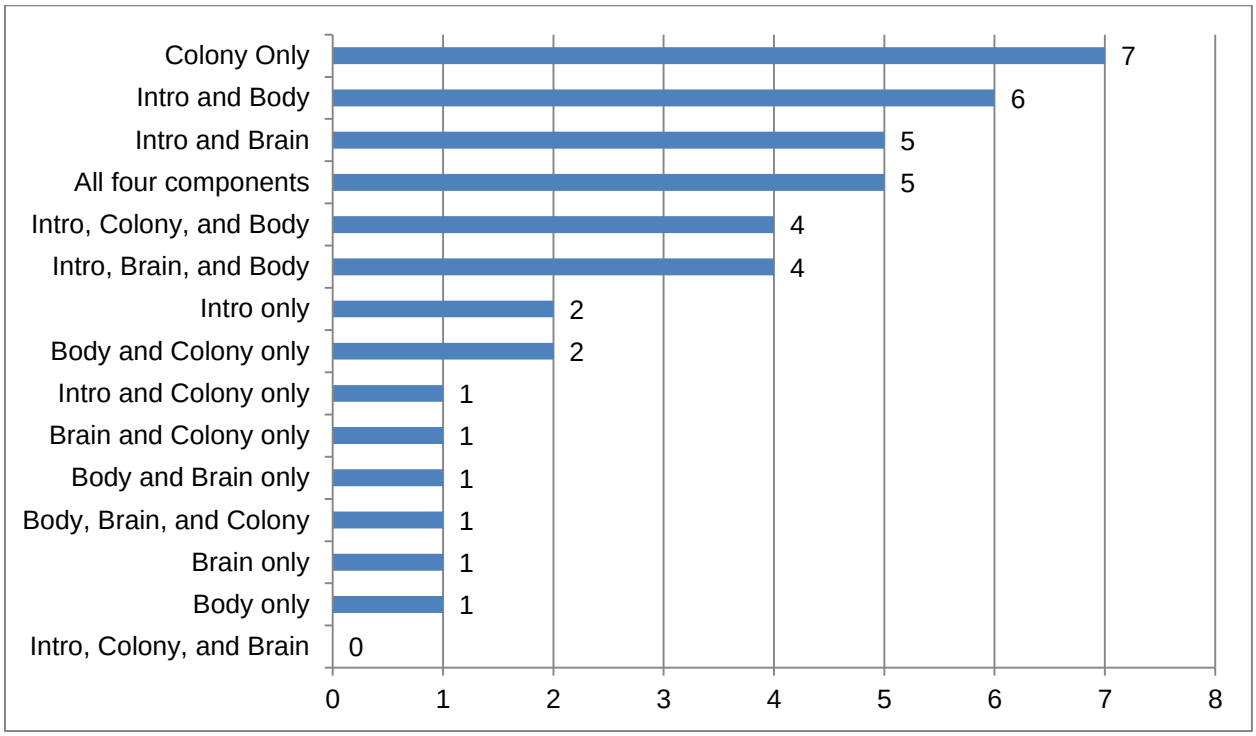


Figure 13 shows what combinations of components visitors tended to visit. The median number of exhibition components visited was two, and the median number of interactive components visited was one, suggesting that visitors tended to go to the Intro Section and one of the interactive components. Indeed, 25 groups visited the Intro Section and at least one other component, most often including the Body Lab (Figure 13). Visitors were often observed stopping at Body Lab on the way into or out of the *Theater of Electricity*, and then, if interested, walking to the Intro Section to learn more.

1.2 The core interactive components were generally used thoroughly by the visitors who interacted with them.

The three core exhibition components—Body Lab, Brain Lab, and Colony Lab—were each designed to illustrate a challenge that the RoboBees team faces during development of the RoboBee. For example, at the Colony Lab, visitors play a game in which they control a colony of RoboBees, directing them to accomplish the task of pollinating eight flowers as efficiently as possible. At Brain Lab, visitors choose a combination of three sensors and a battery that allow the RoboBee to perform necessary functions. At Body Lab, visitors explore two representations of pop-up hinges and watch a short video of the real RoboBee pop-up construction. Thus, thoroughly using the component would involve the visitor completing the component's main activity at least once. For each core interactive component, at least half of the visitors who used the component used it thoroughly (Table 1).

TABLE 1. Post Group: Descriptions of Thorough Use of Each Interactive Component (N=41).

Component	Action	Percentage of Groups Completing Action
Body Lab	Lifted simple pop-up, lifted complex pop-up, and watched video	50%
Brain Lab	Found at least one successful combination of sensors	61%
Colony Lab	Completed at least one round of the pollination game	57%

Some of those visitors used the components even more thoroughly. For instance, the Colony game is designed to encourage visitors to retry the game after completing it once in order to improve their efficiency. 33% of visitors to the Colony Lab component retried the game after completing it once. The visitors who retried the Colony Lab activity completed it an average of 3.4 times. In addition, while 61% of visitors to Brain Lab found at least one successful combination of sensors for the bee, 22% of visitors to Brain Lab found both successful combinations.

These findings indicate that visitors did not generally use the whole exhibition. Instead, they tended to use the Intro panel and at least one of the interactive components, most often the Body Lab. These findings also show that visitors tended to thoroughly use the interactives that they went to. This included at least half of the visitors to each interactive component completing the component's main activity at least once, with a subgroup of these visitors using the components more thoroughly. The fact that visitors seem to use the exhibition components thoroughly may go together with the fact that they are not using the entire exhibit: getting background information from the Intro Section and then engaging thoroughly with one interactive component may be a satisfying interaction for visitors. Visitors may also have been limited by time and other external factors.

2. HOW DOES VISITING THE *MICROROBOTICS TAKES FLIGHT* EXHIBITION IMPACT VISITOR UNDERSTANDING OF THE ASSOCIATED MAIN MESSAGES AND LEARNING GOALS?

In order to understand how, if at all, the exhibition impacted visitor understanding of associated main messages, evaluators interviewed and surveyed visitors who had used the exhibition. These visitors' responses were compared to interview and survey responses of Museum of Science visitors who had not used the *Microrobotics Takes Flight* exhibition. The following sections describe visitor understanding of the different main messages. The findings include the following:

2.1 Visitors to the *Microrobotics Takes Flight* exhibition had a greater understanding of the challenges researchers face when building tiny flying robots and the strategies they use to overcome them than people who did not visit the exhibition.
2.2 Visitors to the *Microrobotics Takes Flight* exhibition identified many different uses for the RoboBee, and most recognized that the project is not yet finished.

2.3 Few visitors talked about how the RoboBees team broke down the problem of building a tiny flying robot by breaking into specialized teams.

2.1 Visitors to the Microrobotics Takes Flight exhibition had a greater understanding of the challenges researchers face when building tiny flying robots and the strategies they use to overcome them than people who did not visit the exhibition.

When looking across multiple data sources, it appears that the *Microrobotics Takes Flight* exhibition is effective in its goal of facilitating visitor understanding of the challenges researchers face when building tiny flying robots. These challenges included mass production of the RoboBee, powering the bee, designing a small battery for it, balancing functions and weight, and more.

One indication of this comes from looking at the surveys visitors filled out after being interviewed. Visitors in the Post group took a survey with Likert scale items related to the exhibition's main messages and rated them in a retrospective before-and-after fashion after visiting the exhibit. 71% of Post visitors increased their rating in the "After" column for the statement "I know about some of the challenges researchers face when building tiny flying robots." Additionally, 49% of visitors increased their rating of their agreement with the statement "I know about some of the strategies researchers use to overcome those challenges" (see Table 2). These data indicate that most *Microrobotics Takes Flight* visitors felt the exhibition had influenced their knowledge of the challenges related to creating RoboBees.

TABLE 2. Post Group Retrospective Ratings of Message Related Survey Items (N=41).

Item	Number of Respondents Increasing Their Rating	Percent Increasing Their Rating
I know about some of the challenges researchers face when building tiny flying robots	29	71%
I know about some of the strategies researchers use to overcome those challenges	20	49%
Research teams may need to develop innovative methods to solve new research challenges.	15	37%
Researchers may need to break into specialized teams to solve large research problems.	14	34%
Research projects involve diverse groups of people encompassing a range of specialties and expertise.	7	17%

Differences also emerged when comparing the "After" ratings for Post group to the Pre group (Table 3). Pre group visitors, who had not used the exhibition, rated their agreement with the same statements related to the exhibition's main messages to enable comparison to the Post group. Post group ratings of agreement with the exhibition exit survey statement, "I know about

some of the strategies researchers use to overcome these challenges" were significantly higher than Pre group ratings on the same statement[1]. This indicates that the exhibition impacted visitors' understandings of the strategies the team used to solve the challenges (e.g. creating pop-up technology for faster production) that were involved with creating a RoboBee.

TABLE 3. Pre and Post Group Ratings of Exhibition Message-Related Survey Items (N=81).

Survey Statement	Pre Mean	Pre Standard Deviation	Post Mean	Post Standard Deviation
I know about some of the challenges researchers face when building tiny flying robots.	3.4	1.3	4.0	0.9
I know about some of the strategies researchers use to overcome these challenges.*	2.9	1.3	3.6	1.1
Research teams may need to develop innovative methods to solve new research challenges.	4.2	1.2	4.5	0.6
Researchers may need to break into specialized teams to solve large research problems.	4.2	1.2	4.3	1.0
Research projects involve diverse groups of people encompassing a range of specialties and expertise.	4.5	0.9	4.6	0.8

*Indicates that differences are significant at the p<.05 level.

Open-ended responses to interview questions also show that exhibition visitors gained an understanding of the research challenges involved in building tiny flying robots. In the interview, visitors were first asked a series of interest- and learning-related questions. When asked what was most interesting about the exhibition, what the Museum was trying to have them learn from it, and what if anything they learned from it, 17 (of 41) visitor groups mentioned research challenges or the innovative methods the RoboBees team is using to solve them. This was the most common message brought up by the visitor groups (Table 4). Although few visitors directly stated the message "The RoboBees team is developing innovative methods to solve research challenges," they did point out specific innovations or challenges that the team faced. Examples of the kinds of responses visitors gave that fit into this message include:

- [M1, 56]: …Battery issue—once they work that out it won't be tethered.
- [M1, 23]: What types of sensors—never thought about having light sensors. All different types of stimuli [that the RoboBee could respond to]. [F1, 23]: I thought more battery would be better, but it was too heavy. [M1, 23]: That's a limitation.
- [M1, 10]: How pollination works. Efficiency. How to be organized. Certain flowers for certain amount of bees.

[1] U=565.5, Z=-2.471, p=.013.

TABLE 4. Post Group Responses to Interest and Learning Questions (Q1-Q3) (N=41).

Code	Number of Groups	Example
Primary message: The RoboBees team is developing innovative methods to solve research challenges	17	[M1, 58]: Never knew that you had to make special batteries part of research--get on board with bee.
Primary message: The RoboBees team broke down the problem by creating specialist research teams for development of the body, brain, and colony	0	N/A
Secondary message: RoboBee technology could be used for many different applications in the future…	17	[F1, 62]: …Could be used for negative things. Hope it's used for [good].
Secondary message: The RoboBees team includes a diverse group of people encompassing a range of specialties and expertise	2	[M1, 17]: …It needs like 10 different engineers. You can't just have one engineer.
Secondary message: ...but the project is not yet finished	1	[F1, 62]: …Not here yet, but coming.

Full response tables for the interest and learning questions are in Appendix D.

Later in the interview, Post visitors were asked to talk in general about the process researchers go through when creating tiny flying robots. Pre visitors were asked this question as well. Once again, Post visitors came up with a variety of ideas, including naming some of the challenges researchers would face when working on this problem (see Table 5). While people in the Pre and Post group both addressed specific challenges faced by the researchers, when looking at how many visitor groups mentioned any research challenges or strategies in response to this question, more Post groups than Pre groups mentioned any research challenges or strategies. Twenty-one Post visitor groups mentioned research challenges or strategies compared to 16 Pre visitor groups. Some groups mentioned multiple research challenges and/or strategies, but still more Post group responses fell into specific research challenge or strategy categories than Pre group responses (30 Post responses versus 22 Pre responses). Some examples of research challenges and strategies mentioned by Post groups were:

- The small size of the robot: [M1, 12]: Having to fit everything in a small space. …Start bigger and see if they can minimize the pieces.
- The weight of the robot: [F1, 28]: … Find materials that are light enough.
- Powering robot: [M1, 12]: … They don't have a battery.
- Functions of the bee: [M2, 14]: First think about the sensors and batteries to use, which would be best.
- Mass production of the RoboBee: [F1, 52]: …One [team] that works on how to manufacture many.

TABLE 5. Responses to Question 5, "Think about a team of researchers trying to create tiny flying robots. Can you talk in general about the process the researchers might go through to make those robots?" (N=41).

Code	Number of Post Groups	Number of Pre Groups	Example
Researchers engaged in the engineering design process--asking questions, imagining possibilities, planning, building, testing, and improving	17	21	Post: [M2, 14]: Need a problem to solve. Sketch out ideas, build a prototype and see problems. Refine prototype, final version.
Researchers include a diverse group of people encompassing a range of specialties and expertise	10	7	Post: [M1, 27]: …Team with different areas of expertise: biology, electrical, mechanical--a team to do work on the design….
Researchers studied real bees, insects, or things in nature in the process	10	13	Post: [F1, 22]: RoboBee… they used biomimicry. Inspired by nature. I did a whole class on biomimicry.
Researchers face research challenges related to the small size of the robot	9	5	Post: [M1, 48]: Working with that small size.
Researchers face research challenges related to powering the robot	8	12	Post: [M1, 23]: Power supply was mentioned. They don't seem to hold a charge for long…
Researchers face challenges related to choosing the robot's functions/sensors	7	5	Post: [M1, 24]: Cars have to have sensors, so I imagine this is similar. The bees need a sense of balance, a lot of mobility. How they would crack that I don't know.
Researchers develop innovative methods for mass production	6	0	Post: [M1, 31]: Cost effective, mass-producing.
Researchers must choose materials	6	18	Post: [F1, 32]: 1. Ask a lot of questions: …What materials? …
Engineers or people in general people work on the robot	6	15	Post: [F1, 28]: …Design done by engineers….
Researchers look for funding	5	9	Post: [M1, 21]: A lot of money.
Other	5	6	Post: [F1, 65]: I'm just blown away that they're doing this.
Researchers face research challenges involving the weight of the bee	4	6	Post: [M1, 48]: Need materials that are lightweight enough.
Researchers broke down the problem by creating specialist research teams for development of the body, brain, and colony	4	0	Post: [M1, 58]: Well-- they broke down pretty well. Material scientists to make lightweight, computer programmer. Need mechanical engineers, computer scientists, electrical engineers. Got to be a boss to that. Does everyone listen to him?
Researchers do programming and modeling	3	5	Post: [F1, 20]: How to go about it. Write small program, beta robot.
I don't know	2	1	Post: [M1, 24]: Can I skip this one?
Researchers study related projects	0	11	Pre: [F1, 37]: Research other tiny robots that don't fly, adjust them.

These data indicate that after visiting the exhibition, visitors to the *Microrobotics Takes Flight* exhibition have a greater understanding of the challenges researchers face when creating tiny flying robots. Post group visitors rated themselves as having greater understanding of these challenges after visiting the exhibit, and were also significantly more likely than the Pre group to agree that they understood some of the strategies researchers use to overcome these challenges. Responses to the open-ended interview questions about interest and learning indicate that Post groups brought up research challenges more than they brought up other main messages. Responses to the broad comparison interview question about the process of creating tiny flying robots show that Post groups mention research challenges more often than Pre groups.

One possible reason that visitors mentioned challenges could be the structure of the exhibition. Each of the interactive components is structured around a research challenge and the way each RoboBees sub-team is attempting to solve that challenge. Since visitors tended to visit the Intro Section and at least one other component, they would have been exposed to this content in at least one interactive component. The Intro Section also includes videos and artifacts that allow visitors to understand exactly how small the RoboBee is and how hard it is to power it, which are two challenges that visitors mentioned. Another possibility is that the research challenges were especially interesting to visitors, most of whom were learning about the RoboBees project for the first time. Research challenges play a direct role in the RoboBees project being unfinished, which is another main message that the exhibition team emphasized in the exhibition.

2.2 Visitors to the Microrobotics Takes Flight exhibition identified many different uses for the RoboBee, and most recognized that the project is not yet finished.

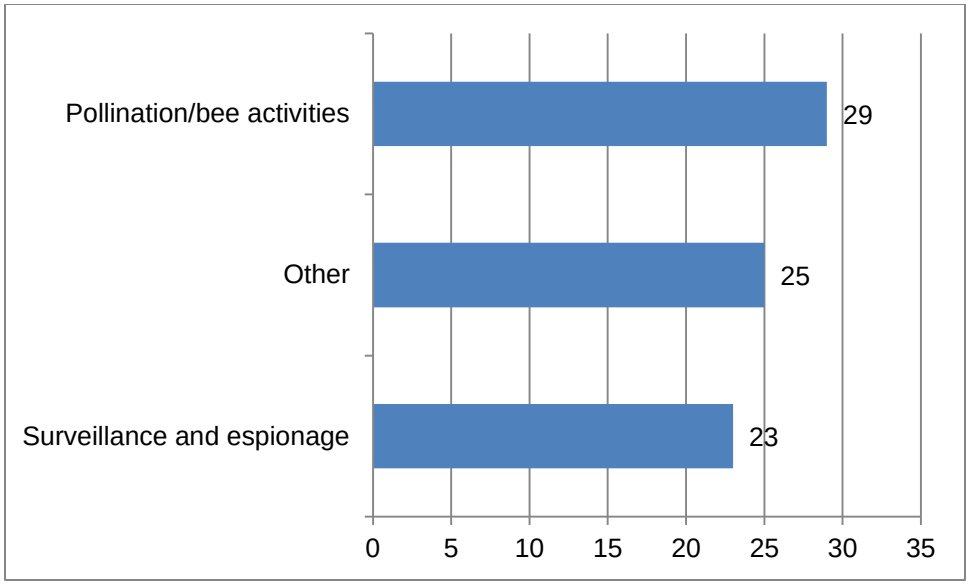
Visitors seemed to understand that the RoboBee has many potential uses, though some potential applications were mentioned more than others. When asked what was most interesting about the exhibit, what the Museum was trying to have them learn, and what they learned, 17 (of 41) visitor groups talked about future uses of the RoboBee (see Table 4). This was tied as the most common response visitors gave across these questions. Examples of visitor responses that fell into this category included the following:

- [F1, 27]: I went to look further, want to know what they were used for. I thought it was interesting that they could be a solution for colony collapse disorder.
- [F3, 21]: Helps us with pollinating. It said in the video.
- [M1, 12]: The purposes--military stuff. [F1, 65]: Why we're doing it.

During the interview, data collectors also asked visitors to try to think of two potential uses for the RoboBee. Most visitor groups (21 of 41 groups) thought of two uses, and eight groups thought of three uses. 11 thought of just one use, and one group did not answer the question. By far the most common uses visitors thought of were pollination and military surveillance. Of the 40 groups asked this question, over two-thirds (73%) mentioned these two uses. Examples of these responses included the following:

- Pollination: [M2, 13]: Pollinate flowers. [M3, 67]: Obviously pollinating.
- Surveillance and espionage: [M1, 58]: A new drone, type of drone.

FIGURE 14. Post Group Responses to "What are two things you think a RoboBee could be used for?" (N=40).



The "other" category contains 10+ other uses that visitors thought of, including: search and rescue, medical applications, environmental uses, carrying loads, exploring, seeing small objects, and more. Examples of these visitor responses included the following:

- [F1, 27]: Search and rescue.
- [M2, 12]: Fly into the human body…
- [M1, 48]: Mini probes, if you could get small fiber optics on it.

These data indicate that visitors could identify many different uses for the RoboBees after using the exhibition. Visitors were most likely to identify pollination and surveillance as uses. The pollination connection is most likely because the robots are called "RoboBees," so it is sensible that they could be used to pollinate. Surveillance is also a potentially controversial topic, so visitors may be more likely to remember it. However, they still thought of other uses. This may be because the exhibition identifies not just two, but four example uses on each component (pollination, surveillance, search and rescue, and environmental uses), so some visitors were able to see beyond pollination and surveillance.

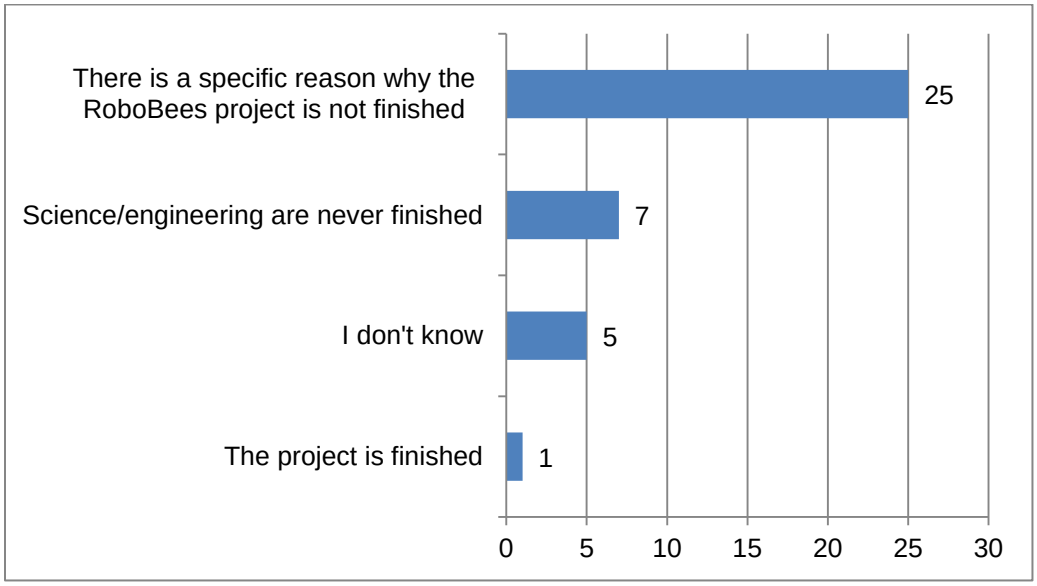
It was also important to the exhibition team that visitors understand that the RoboBees were still a work in progress. Data collectors had one visitor in each group take a survey that included an item asking the visitor to rate their agreement on a scale of 1 to 5 (with 1 being "Strongly Disagree" and 5 being "Strongly Agree") with the statement: "The RoboBees project is finished." In the interview, data collectors probed for the reasoning behind that rating.

On average, visitors rated their agreement with the statement as 2.3 out of 5 (standard deviation 1.0), meaning they generally disagreed with the statement. When asked why they chose that rating, most visitors said it was because of a specific reason they saw in the exhibition such as:

- [M1, 58]: Apparently they have a lot to do, don't even have it flying yet.
- [F4, 36]: Doesn't seem like they are finished. Still tethered.
- [M2, 14]: Because it could be smaller and sensors could be improved for highest quality.

Figure 15 shows the different reasons visitors gave for their ratings. Only one exhibition visitor thought the project was finished.

FIGURE 15. Reasons the Post Group Gave for Their Level of Agreement with the Statement, "The RoboBees Project is Finished" (N=39).



These data indicate that visitors understood that there are many possible uses for the RoboBee. These uses include pollination and surveillance/espionage, among others like search and rescue or medical uses. These data also indicate that visitors understood that the RoboBees project is not complete. These findings are probably a result of emphasized content in the exhibit. The Intro Section in particular makes it clear that the project is not finished, as it contains videos of the RoboBees flying tethered to a computer and other content about how the project is not finished. Since the Intro Section was the most-visited component, many visitors saw this content. Several visitors mentioned the lack of a battery when asked why they said the project was not finished (for examples, see the bulleted list above).

2.3 Few visitors talked about how the RoboBees team broke down the problem of building a tiny flying robot by breaking into specialized teams.

Overall, few visitor groups addressed the primary message that "The project leads broke down the problem by creating specialist research teams for development of the body, brain, and colony." Across interview questions, this message was mentioned only four times in the Post group and not at all in the Pre group.

One survey item, "Researchers may need to break into specialized teams to solve large research problems," directly addressed this message. There was not a statistically significant difference in agreement with this statement between the Pre group and the Post group (see Table 3). The respective Pre and Post means of 4.2 and 4.3 and the median rating (5 out of 5 in both cases) suggest that this concept may be intuitive to visitors and not necessarily something they learned from the exhibit.

No visitor groups mentioned breaking down the problem in response to the first three interview questions related to interest and learning (see Table 4). In response to Question 5, "Talk about the process researchers go through when designing tiny flying robots," only four visitor groups talked about how the team broke down the problem (see Table 5). Responses in this category included the following:

- [F1, 52]: It said they are actually creating three teams. One for physical materials, software and programming, a third… colony? One that works on how to manufacture many.
- [F1, 47]: …Then break down the system into pieces. With every piece, find domain experts to work on it. But optimize each and every piece. Have to compromise for system-level integration.
- [F1, 30]: How to build, power, program.

In general, the message about "breaking down the problem" did not come through very often in visitor responses. One possible explanation is that visitors may not have addressed this message not because they did not understand it, but because other aspects of the RoboBees project were more noteworthy to them. These other noteworthy aspects include the mere existence of the project, the small size of the bees, and the challenges the researchers face in the process of creating the RoboBee. Another possible explanation for this stems from the ways visitors used the exhibition. Since most visitor groups did not visit all three interactive components, the message about the three different teams may not have come through as clearly.

3. HOW DOES VISITING THE *MICROROBOTICS TAKES FLIGHT* EXHIBITION IMPACT VISITORS' INTEREST IN OR KNOWLEDGE ABOUT ENGINEERING?

In order to understand how, if at all, the exhibition impacted visitor interest in or knowledge of engineering, evaluators interviewed visitors, asking them if they did anything in the exhibition like what an engineer does, and surveyed them, asking general interest and learning questions about engineering. These visitors' responses were compared to interview and survey responses of Museum of Science visitors who had not used the *Microrobotics Takes Flight* exhibition. The following sections describe findings related to visitor interest in or knowledge of engineering. The findings include the following:

> 3.1 *Microrobotics Takes Flight* exhibition visitors had a high interest in engineering prior to visiting and felt that what they did in the exhibition was like what an engineer does.

3.1 Microrobotics Takes Flight exhibition visitors had a high interest in engineering prior to visiting and felt that what they did in the exhibition was like what an engineer does.

The visitor survey included several survey items related to engineering. Visitors in both the Pre and the Post groups answered these questions, and visitors in the Post group rated them in a retrospective before-and-after fashion after visiting the exhibition. In the Post group's retrospective ratings, average ratings for both the "Before" items were generally high. Mean ratings for the "Before" items were 4.0 for "I know how engineering can be used to help society" and 3.6 for the other three items. However, some visitors increased their ratings of the statements. About 30% of groups increased their agreement with the statements "I know what engineers do" and "I know how engineering can be used to help society." About 20% increased their agreement with the statements "I know how engineering is different from science" and "I am interested in engineering" (see Table 6). This shows that not many people increased their ratings because they were already fairly interested in and knowledgeable about engineering prior to going into the exhibition. Recall from Figure 11 in the Methods section that about two-thirds of the Post group reported that they had a "Medium" or "High" background in science or engineering.

TABLE 6. Post Group Retrospective Ratings of Engineering-Related Survey Items (N=41).

Item	Number of Respondents Increasing Their Rating	Percent Increasing Their Rating
I know what engineers do	12	29%
I know how engineering can be used to help society	13	32%
I know how engineering is different from science	8	20%
I am interesting in engineering (n=40)	7	18%

Data collectors also asked visitors if they did anything in the exhibition that was like what an engineer did. 52% of groups had at least one member who answered yes to this question. They were further asked how what they did was like what an engineer does. Visitors responded in several ways (see Table 7), most often discussing aspects of the Brain Lab activity, such as "The Brain Lab, tried to optimize—how to get the best result out of the bee." Visitors also mentioned other things, such as problem-solving. For example, one visitor said, "You made the decision for the bees and figured out the directions and learned by trial and error. Engineers do that."

TABLE 7. Post Group Reports of What They Did That Was Like What an Engineer Does (N=22).

Code	Number of Groups	Example
Choosing sensors, batteries, or parts for the RoboBee	9	[M1, 11]: We needed to figure out what equipment to put in the bee. Not to put too much weight in them.
Mentions a specific activity from an exhibition component	5	[F1, 26]: Yes, played with blocks.
Engineers work on efficiency	4	[M1, 63]: Yes, in research and how to… I think it was trying to show you that the research has several variables, minimize the time, correlations between variations…
Problem-solving or trial and error	4	[F1, 42]: Problem solving. Think analytically.
Engineers observe	2	[M1, 56]: Observing is what we do. Looking at the video was neat.
Engineers use modeling	1	[M1, 58]: Modelling-- using a model to explore how pollination works.
Engineers are hands-on	1	[M1, 24]: Hands-on experience, I guess.
Engineers think about materials	1	[M1, 48]: Thought about how it all works. More curious about construction materials.

One interesting thing to note is that visitor groups seemed to connect the Brain Lab activities to engineering more than Colony Lab or Body Lab. Nine visitors gave a description of the Brain Lab activity when asked what they did in the exhibition that was like what an engineer does. Additionally, three of the five visitors who referred to specific components or described specific activities from the exhibition (e.g. "playing with blocks") described the Brain Lab. In contrast, 2 visitor groups said specifically that Body Lab was "not interactive" in response to this question, perhaps because its associated activity has no puzzle for the visitor to solve as in the other two core interactive components.

The 52% of visitors recognizing how what they did was like what an engineer does is comparable to what visitors have said after interacting with other engineering-related exhibitions or programs. 40% of girls aged 8-14 who were interviewed in a 2013 summative evaluation of the Design Challenges Program at the Museum of Science, Boston said they did something like what an engineer does at the activity (Auster, 2013). Researchers also found that girls 11 and older were significantly more likely than younger girls to say they did something like what an engineer does in the activity. Thus, older visitors in the Design Challenges summative sample were more able to recognize that they did something like what an engineer does. The sample for the *Microrobotics Takes Flight* summative evaluation included older children as well as adults. Therefore, this might be why even more of them were able to recognize things they did in the exhibition that were like what an engineer does. This finding also shows that visitors can recognize elements of engineering practice in a traditional exhibition format as well as they can in a hands-on program.

IV. CONCLUSION

The summative evaluation of the *Microrobotics Takes Flight* exhibition suggests that overall, the exhibition achieved most, but not all, of its goals. The exhibition was successful in getting visitors to recognize the challenges of creating tiny flying robots like RoboBees, understanding the possible uses of the RoboBee, and recognizing that the RoboBees project is not finished. In addition, the exhibition was successful in helping visitors to understand that what they were doing is something like the engineering process. The exhibition was less successful in getting visitors to understand how the team broke down the problem by creating specialized teams.

There were several data points showing that visitors to the *Microrobotics Takes Flight* exhibition gain an understanding of the challenges researchers face when creating tiny flying robots. Post group visitors rated themselves as having greater understanding of these challenges after visiting the exhibition, and were also significantly more likely than the Pre group to agree that they understood some of the strategies researchers use to overcome these challenges. Responses to the open-ended interview questions about interest and learning indicate that Post groups brought up research challenges more than they brought up other main messages. Finally, responses to the broad comparison interview question about the process of creating tiny flying robots show that Post groups mention research challenges more often than Pre groups.

Post group visitors also recognized that the RoboBees project has many possible uses for its end product. Visitors most often identified pollination and surveillance as uses for the RoboBee, but many other possibilities also arose. Post group visitors also clearly understand that the project is not yet finished, whether because of general awareness that science is always evolving and changing or because they knew a specific reason from the exhibition for the RoboBees project not being done yet.

Visitors may have picked up on the research challenges because the exhibition was designed to evoke them. Each interactive component was structured around the way one of the RoboBees sub-teams approached a different research challenge. A visitor who experienced any of these components would have been able to gain hands-on understanding of a research challenge, especially in the cases of Brain Lab and Colony Lab, where the visitor solves a puzzle to complete the activity. The Intro Section also provided information about research challenges. Since visitors tended to visit the Intro Section and at least one interactive component, they were able to understand some of the challenges.

However, few visitor groups addressed the primary message that "The project leads broke down the problem by creating specialist research teams for development of the body, brain, and colony." Across interview questions, this message was mentioned only four times in the Post group and not at all in the Pre group. One explanation for this is that this message was not as clear because most visitors did not visit the whole exhibition (only 5 of 41 groups did) or every interactive component (1 of 41 groups). Even though content about "breaking down the problem" was present in other places, experiencing all three interactive components may have reinforced the concept. Another explanation for why visitors did not mention the "breaking down the problem" message is because they already understood it or it felt enough like common sense to them that they did not mention it. For example, one survey item, "Researchers may need to

break into specialized teams to solve large research problems," directly addressed this message. The respective Pre and Post means of 4.2 and 4.3, the median rating (5 out of 5 in both cases), and the fact that there were no statistically significant differences suggest that this concept may be intuitive to visitors and not necessarily something they learned or did not learn from the exhibit.

In relation to the additional evaluation question about the exhibition's impacts on visitor interest in or knowledge of engineering, the exhibition seems to have not affected their interest in and knowledge of engineering. This is likely because visitors in the Pre and Post groups also tended to have some background in science or engineering, and thus a relatively high degree of interest and familiarity in engineering and/or science. However, over half of visitors were able to recognize that they did things in the exhibition like what an engineer does. This shows that visitors can recognize elements of engineering practice in a traditional exhibition format.

Overall, though, the *Microrobotics Takes Flight* exhibition seems to be successful in meeting most of its goals. In particular, visitor groups seem to understand that the exhibition was about not only the final product—the RoboBee—but also the process of creating it. Visitors recognized and got hands-on experience with some of the research challenges, understood that the project was not yet finished, and also identified some things they did in the exhibition that were like what an engineer does.

REFERENCES

Auster, R. &.-S. (2013). *Girls' Participation in Design Challenges: Summative Evaluation Report.* Boston: Museum of Science, Boston.

APPENDIX A: TRACKING AND TIMING

***Microrobotics Takes Flight* Summative Evaluation**
Visitor Tracking and Timing

Visitor Information

Adult F ___ # Adult M ___ # >8 Child F ___ # >8 Child M ___

Group type:
☐ Adults only ☐ Adults and kids ☐ Other: _____

Did the group visit:

☐ Intro Section
- ☐ Used hearphone
- ☐ Discussed with group members
- ☐ Watched intro video (right side)
- ☐ Watched spin browser video (left side)
- ☐ Turned spin browser wheel (left side)

☐ Body Lab
- ☐ Used hearphone
- ☐ Discussed with group members
- ☐ Watched video
- ☐ Lifted simple pop-up
- ☐ Lifted complex pop-up (with lever)

☐ Colony Lab
- ☐ Discussed with group members
- ☐ Completed activity
- ☐ Retries activity after completing

Number of times group completes activity: _____

☐ Brain Lab
- ☐ Successful combo present at start
- ☐ Used hearphone
- ☐ Used audio screen readout (large square button)
- ☐ Discussed with group members
- ☐ Tested any sensors or batteries
- ☐ Found one successful combination
- ☐ Found two successful combinations

☐ Focus visitor (if applicable): _____

Other Notes (who used the different components, conversations between visitors, questions about vocabulary/instructions, misuse of exhibits):

APPENDIX B: VISITOR INTERVIEWS

***Microrobotics Takes Flight* Summative Evaluation**
Visitor Interview

1. What are the ages and genders of your group members?

Group Member	Age	Gender
1		
2		
3		
4		
5		
6		
Other group members:		

2. What did you find most interesting about the exhibit?

3. What do you think the Museum was trying to have you learn about in this exhibit? [Probe]: Is there anything else you think the Museum was trying to have you learn about here?

3. What, if anything, did you learn that you did not know before? [Probe]: Did you learn anything else that you did not know before?

4. Did you do anything in this exhibit like what an engineer does? If so, what was that?

5. Think about a team of researchers trying to create tiny flying robots. Can you talk in general about the process the researchers might go through to make those robots? [Probe: Who might work on this project? What challenges might they face? How might they go about solving those challenges?] **[Note: Please write down or circle any probes you use.]**

6. What are two things you think the RoboBee could be used for?

7. Would you characterize your background in engineering OR science as low, medium, or high?

☐ Low ☐ Medium ☐ High (Visitor: _____)

Other visitors:
☐ Low ☐ Medium ☐ High (Visitor: _____)
☐ Low ☐ Medium ☐ High (Visitor: _____)
☐ Low ☐ Medium ☐ High (Visitor: _____)

7a. If Medium or High, please describe:

[Hand them the survey, let them fill it out, then take it back and look at Q1]

8. I see you marked [number] for question 1. Can you tell me why you chose that rating?

9. Is there anything else you'd like to add?

***Microrobotics Takes Flight* Summative Evaluation**
Non-Visitor Interview

1. Have you and group members looked at this exhibition about RoboBees before?
___YES ___ NO → [If yes:] "Thanks, have a great day!"

2. [If no, continue with the interview]: What are the ages and genders of your group members?

Group Member	Age	Gender
1		
2		
3		
4		
5		
6		
Other group members:		

3. Think about a team of researchers trying to create tiny flying robots. Can you talk in general about the process the researchers might go through to make those robots? [Probe: Who might work on this project? What challenges might they face? How might they go about solving those challenges?] **[Note: Please write or circle any probes you use.]**

4. Would you characterize your background in engineering OR science as low, medium, or high?
☐ Low ☐ Medium ☐ High (Visitor: _____)

Other visitors:
☐ Low ☐ Medium ☐ High (Visitor: _____)
☐ Low ☐ Medium ☐ High (Visitor: _____)
☐ Low ☐ Medium ☐ High (Visitor: _____)

4a. If Medium or High, please describe:

APPENDIX C: VISITOR SURVEYS

***Microrobotics Takes Flight* Summative Evaluation**
Visitor Survey

1. Please rate your agreement with the following statement:

	Strongly disagree				Strongly agree
The RoboBees project is finished.	1	2	3	4	5

2. Had you heard of the RoboBees project at Harvard University before today? ☐ Yes ☐ No

3. Please rate your level of agreement with the following statements before and after using the RoboBees exhibit today.

   When answering the questions, please answer them about researchers and engineers in general, not just the ones working on the RoboBees project.

	BEFORE using the RoboBees exhibit					**AFTER using the RoboBees exhibit**				
	Strongly disagree				Strongly agree	Strongly disagree				Strongly agree
I know what engineers do.	1	2	3	4	5	1	2	3	4	5
I know how engineering can be used to help society.	1	2	3	4	5	1	2	3	4	5
I know how engineering is different from science.	1	2	3	4	5	1	2	3	4	5
I am interested in engineering.	1	2	3	4	5	1	2	3	4	5
I know about some of the challenges researchers face when building tiny flying robots.	1	2	3	4	5	1	2	3	4	5
I know about some of the strategies researchers use to overcome these challenges.	1	2	3	4	5	1	2	3	4	5
Research teams may need to develop innovative methods to solve new research challenges.	1	2	3	4	5	1	2	3	4	5
Researchers may need to break into specialized teams to solve large research problems.	1	2	3	4	5	1	2	3	4	5
Research projects involve diverse groups of people encompassing a range of specialties and expertise.	1	2	3	4	5	1	2	3	4	5

***Microrobotics Takes Flight* Summative Evaluation**
Non-Visitor Survey

1. Had you heard of the RoboBees project at Harvard University before today? ☐ Yes ☐ No

2. Please rate your level of agreement with the following statements.

	Strongly disagree				Strongly agree
I know what engineers do.	1	2	3	4	5
I know how engineering can be used to help society.	1	2	3	4	5
I know how engineering is different from science.	1	2	3	4	5
I am interested in engineering.	1	2	3	4	5
I know about some of the challenges researchers face when building tiny flying robots.	1	2	3	4	5
I know about some of the strategies researchers use to overcome these challenges.	1	2	3	4	5
Research teams may need to develop innovative methods to solve new research challenges.	1	2	3	4	5
Researchers may need to break into specialized teams to solve large research problems.	1	2	3	4	5
Research projects involve diverse groups of people encompassing a range of specialties and expertise.	1	2	3	4	5

APPENDIX D: SUPPLEMENTARY DATA

TABLE 8. Post Group Responses to Question 1, "What was most interesting to you about the exhibit?" (N=41).

Code	Number of Groups	Example
The RoboBee's small size was interesting	13	[M1, 56]: Amazing how they can make something that small…
The general features of the exhibit were interesting	10	[M2, 10]: The game and the popups and video. [M1, 13]: The game. Liked how it has a model of one [RoboBee model].
I didn't know the RoboBees project existed	9	[M2, 81]: What I found interesting was I had no idea such a project was underway.
What the RoboBee will do (fly, be independent, etc.) was interesting	8	[F1, 52]: Little RoboBee is incredible…the fact that it can fly.
The RoboBees team is developing innovative methods to solve research challenges	6	[F1, 32]: The fine tuning. Which sensors to put on.
RoboBee technology could be used for many different applications in the future…	6	[M1, 12]: The purposes--military stuff. [F1, 65]: Why we're doing it.
General thoughts about RoboBees, e.g. "How it works"	4	M1, 63]: Demonstrate how research is done.
I'm an engineer or technical person	4	[M1, 24]: …I was a math kid, so having it explained this way made things easier for me.
Asks questions about purpose or effects	3	[F1, 47]: …But to be honest I would like to see the purpose or use of the technology. Maybe I didn't see it. It's hard to build, but what's its purpose?
I don't know/I'm not sure/I didn't read much	3	[M1, 24]: As I said, didn't look much.
The technological advances of the project were interesting	2	[M1, 64]: The innovation.
Watching a group member use the exhibit was interesting	2	[F1, 67]: Watching him do it.
Bees, colony collapse, or pollination was interesting	1	[M1, 10]: …Bees are dying because of… I forget
There are women working on the RoboBees project	1	[F1, 62]: …Females involved in it, not male dominated.
...but the project is not yet finished	1	[F1, 62]: The fact that I never knew RoboBees existed. Not here yet, but coming.

TABLE 9. Post Group Responses to Question 2, "What do you think the Museum was trying to have you learn about in this exhibit?" (N=41).

Code	Number of Groups	Example
RoboBee technology could be used for many different applications in the future…	12	[F1, 46]: Potential for RoboBees…Things beyond pollination.
The Museum wants me to learn that the team is making technological advances	11	[F1, 23]: How tech is advancing. Nanotechnology.
The RoboBees team is developing innovative methods to solve research challenges	9	[M1, 33]: Tradeoffs. You can't have endless power.
The Museum wants me to learn that there are issues related to bees/colony collapse/pollination	6	[F1, 26]: …Bees going extinct, or that's what I heard, so it's important.
The Museum wants me to learn about RoboBees in general	6	[M1, 29]: About this project and getting in a career path.
The exhibit makes technology and/or engineering accessible	5	[M1, 29]: …Makes the technology relatable to people with no engineering practice.
The Museum wants me to learn that engineering or robotics in general	5	[F3, 21]: Electrical engineering.
I don't know/I'm not sure/I didn't read much	3	[F1, 25]: …Didn't get much out of it.
The Museum wants me to learn about what the RoboBee will do (fly, be independent, etc.)	3	[M1, 56]: …can carry their own programming.
Asks questions about purpose or effects	2	[F1, 62]: …What does RoboBees cost? How does that affect us?
The Museum wants me to learn that the RoboBees is very small	2	[M1, 7]: About tiny robots…
I'm an engineer or technical person	1	[M1, 44]: I am a software engineer.
General thoughts about the exhibit, e.g. "It's interactive"	1	[M1, 58]: … Also fun.
The Museum wants me to learn that Harvard/Northeastern is developing the RoboBee	1	[M1, 58]: Featuring Boston-area scientists-- this is what we're doing in Boston. Not too esoteric.
The RoboBees team includes a diverse group of people encompassing a range of specialties and expertise	1	[F2, ~40]: …Thought the fact that it had to be collaborative was good to know.
The Museum wants me to learn that there are women working on the RoboBees project	1	[F2, 57]: The one we looked at was the girl who went on to MIT. Neat to see a girl do that.

TABLE 10. Post Group Responses to Question 3, "Did you learn anything at the exhibit that you didn't know before?" (N=41).

Code	Number of Groups	Example
I didn't know the RoboBees project existed	22	[M1, 7]; Never knew about that RoboBees exist.
The RoboBees team is developing innovative methods to solve research challenges	7	[M1, 29]: The whole assembly process.
The RoboBees is very small	6	[M1, 12]: That they could have that small.
I don't know/I'm not sure/I didn't read much	5	[F1, 21]: … I didn't really read.
The team is making technological advances	5	[M1, 56]: …Appreciating the new technology.
General thoughts about the exhibit, e.g. "It's interactive"	3	[F1, 46]: …It reinforced what he learned in school.
I'm an engineer or technical person	3	[M1, 56]: I'm an engineer for a medical company.
There are issues related to bees/colony collapse/pollination	3	[M1, 13]: Bees are dying out.
General thoughts about RoboBees, e.g. "How it works"	3	[F1, 17]: That RoboBees were fine.
Harvard/Northeastern is developing the RoboBee	3	[F1, 25]: …that Harvard was developing it.
RoboBee technology could be used for many different applications in the future…	2	[F1, 15]: Using RoboBees to pollinate.
The RoboBees team includes a diverse group of people encompassing a range of specialties and expertise	1	[M1, 17]: …It needs like 10 different engineers. You can't just have one engineer.
There are women working on the RoboBees project	1	[F1, 62]: …2. Female is heading it.
What the RoboBee will do (fly, be independent, etc.)	1	[M1, 31]: Working prototype that can fly.