AC 2012-3734: FAMILY ENGINEERING: EXPLORING ENGINEERING WITH ELEMENTARY-AGE CHILDREN AND THEIR PARENTS

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Family Engineering: Exploring Engineering With Elementary-Age Children And Their Parents

Abstract

The goal of Family Engineering is to actively engage elementary-age youth in exploring engineering activities and career opportunities with their parents. The program addresses both national and global needs for increasing the number and diversity of individuals interested and skilled in science, technology, engineering and mathematics (STEM). Family Engineering promotes 21st Century skills of inquiry, creativity, teamwork, and collaborative problem solving and can be used by individuals and organizations to plan and conduct successful community outreach events that increase public understanding and appreciation of engineering and the role it plays in everyday life. Modeled after the popular publications *Family Science*[1] and *Family Math*[2] a new publication titled *Family Engineering: An Activity and Event Planning Guide*[3] will serve as a valuable resource for professional engineering societies and student chapters of those societies as well as formal and informal educators who want to host a Family Engineering event in their community.

With support from the National Science Foundation, hands-on activities that introduce families to traditional and integrated engineering disciplines and concepts were developed by a team of experienced curriculum developers; field tested at over 40 events in California, Connecticut, Georgia, Michigan, Mississippi, Puerto Rico, Utah, and Wisconsin, to determine their suitability for a wide range of settings and audiences; and reviewed by professional educators and engineers. Formative evaluation guided development of the program and, once completed, summative evaluation conducted by an independent evaluation team measured impact and efficacy of the program's design, resource materials, and event formats. Findings indicate that Family Engineering activities and events are fun and engaging, result in families having an increased appreciation and understanding of engineering, and parents report an increased confidence and willingness to encourage their children to consider a career in engineering.

Introduction

Enrollment in many engineering fields is static or declining and the number of science and engineering graduate students in the U.S. has continued to fall since 1993. However, the demand for scientists and engineers is growing steadily. Unfortunately, the U.S. is unable to meet that demand. The resulting shortage of technically-skilled employees threatens our national economic and technological competitiveness.

Efforts are needed to educate and inspire students to pursue STEM careers. A 2006 report on the Forum *Taking Action Together: Developing a National Action Plan to Address the 'T&E' of STEM*[3] proposes specific actions to build and strengthen the Technology and Engineering pipeline in the U.S. A first step is the goal: "all students will have a basic understanding of technology and engineering and be able to make educated decisions about careers in these

areas." The report favors "early career exploration among students…beginning in middle school *if not before*."

Often pre-college students have not been introduced to science, technology, engineering, and math (STEM) in a way that attracts them to these fields as a career. This has been particularly challenging for the engineering field, since specific instruction in engineering is quite limited in K-12 settings, with most engineering offerings, if available at all, not appearing until the high school years. In an effort to increase awareness, programs such as "Engineering is Elementary" and "Project Lead the Way" have developed curricula that can be used in classroom settings, and programs such as FIRST Robotics have been developed to pique interest in engineering and science though competition. However, none of these programs actively engages parents and children in exploring engineering together.

Parents play an important role in developing their children's career interests by providing support, guidance, career and educational suggestions, and life experiences that support career development (Altman[5]). Therefore, a child's elementary years are an ideal time for engaging parents in informal science and engineering education programs. Because parental influence plays a key role in children's educational achievements, parent/family involvement is an essential part of the solution to the looming STEM crisis. Studies have found that student achievement increased directly with parental engagement (Jordan, *et al.*[6]). When parents participate in their children's education, students' achievement and attitudes improve (Henderson and Berla[7]). Other benefits include higher aspirations for school and career development (Caplan, et al.[8]).

Over the past two decades, two programs have demonstrated the power of parent/child learning in science and mathematics. These programs with their respective publications, *Family Science*, and *Family Math*, have offered teacher/parent trainings and hosted events for families in communities across America and around the globe, successfully engaging families with elementary age youth in hands-on science and math activities and problem solving. By introducing science and math concepts early, these programs are helping to increase parents' and children's interest and confidence in doing science and math, as well as providing parents with resources for encouraging their children to study science and math in school and consider possible careers in these fields. These two programs have been particularly successful at reaching out to families traditionally underserved in science and math, including families from inner urban, rural, and minority communities. Family Math and Family Science offer publications and program delivery in both English and Spanish to assist in reaching diverse audiences.

In its report *Changing the Conversation: Messages for Improving Public Understanding of Engineering*[9], the National Academy of Engineering concluded the public image of engineering needed to reflect the optimism and aspirations of students and needed to be inclusive. Some common misconceptions include: (1) engineering work is a sedentary desk job, (2) engineering is strongly linked to math and science, but not to other vital aspects, such as creativity, teamwork, and communication, and (3) engineers are not seen as directly helping people. NAE observed that many kids want a well-paying job that makes a difference – something that can easily be linked to engineering.

Family Engineering will provide a much-needed vehicle to promote early interest in and a better understanding of engineering through the use of fun, hands-on activities for parents and elementary-aged children. By actively engaging families in these activities, the program increases parental confidence and comfort with encouraging their children to study STEM topics in school and consider a possible career in engineering. The purpose of this paper is to briefly summarize some of the features of the program, and share evaluation data measuring the program's impact and efficacy with the engineering field.

Goals of the Family Engineering Program

The goals of Family Engineering are to: (1) engage families in engineering with fun, hands-on activities, (2) increase public understanding and appreciation of the role engineering plays in everyday life, (3) introduce children at an early age to the many career opportunities in engineering, (4) increase parents' interest in and ability to encourage their children to pursue an engineering career, and (5) provide age-appropriate resources to support volunteers in conducting informal engineering education programs with elementary-aged children and their parents in informal community settings.

In the development phase of the Family Engineering Program, the project team created a list of what families needed to know about engineering:

- Engineering is the use of imagination, along with science and math knowledge, skills, and experience, to address challenges and design solutions.
- Science, math, technology and communication are important tools for engineers
- Engineers are creative problem-solvers
- Engineers improve people's lives and make the world better
- Engineers help shape the future
- Engineering problems usually have multiple solutions
- Engineers are from all races, ethnicities, and genders
- There are many different fields of engineering
- There are a variety of career opportunities in engineering

Family Engineering Program Components

As mentioned above, the Family Engineering program is being modeled after two previously developed and successful programs – Family Science and Family Math. Key program components include the following:

- Publication of a book of hands-on activities titled *Family Engineering: An Activity & Event Planning Guide,* with both English and Spanish language editions completed in 2011. Included in the book are suggestions for how to foster engineering learning in the home and other informal, non-school settings, as well as how to reinforce the importance of science and math course work in school. In addition, the publication provides information and resources for hosting Family Engineering events in school and community settings.

- A variety of tested event formats for implementation by volunteers trained to facilitate and host Family Engineering events in their community. These formats are described in more detail later in this article.
- Professional training opportunities for formal and informal educators, engineers, and STEM college students interested in hosting and/or facilitating Family Engineering events and activities in their community.
- An interactive website with additional resources and materials to support event facilitators, trained volunteers, families, and others interested in implementing Family Engineering in their community.

Family Engineering Activities

A number of dimensions were considered in designing successful activities for Family Engineering. Based on the development team's prior experiences with Family Science and research on teaching and learning in informal settings, the following were identified as important characteristics of a Family Engineering activity:

- *Encourages Family Interaction*: the approach, activity design, and materials invite and encourage parents and caregivers to work and learn together with their elementary-aged children.

- *Fun and Engaging*: activities are informal, enjoyable, and maintain the interest of participants; spark a desire to continue learning about engineering; create positive associations with engineering; create feelings of confidence and ability with relation to engineering

- *Original Material:* activities should provide a new and novel way of exploring engineering concepts; avoid activities that have already been published or are common practice in the informal science, engineering, or enrichment education field.

- *Inherent Engineering Connection*: a connection to engineering content and/or engineering careers is obvious and built in to the context and facilitation of the activity.

- *Approachable and Accessible*: activities require no specialized knowledge of engineering to participate or facilitate; activities are designed so that participants and facilitators feel confident and capable in completing them; activities are appropriate for and inviting to diverse audiences (socially, ethnically, economically, geographically, academically, and culturally).

- *Relevant to Elementary-Aged Children and Their Parents*: activities deal with challenges and subject matter that are relevant, interesting and meaningful to children in grades 1-5 and their parents.

- *Promotes Problem-Solving*: activities encourage finding multiple solutions through inquiry, testing, and teamwork.

- *Simple, Inexpensive Materials*: materials should be easy to acquire, simple to use, and able to be gathered in large quantities for events without a large expense.

- *Safe*: materials and methods for an activity must provide for safe engagement at home or within the open structure of an informal public event. In particular, short activities need to be safe and functional without any facilitation or supervision.

- *Written for Facilitator*: the primary audience for Family Engineering activities is the individual who will be planning and implementing Family Engineering events for elementary-aged children and their families. Parents may also be facilitators in home, school, or community settings.

- *Suitable for a Variety of Settings*: schools, community centers, churches, museums, at home, etc.

In addition to having the above features, there are a number of engineering concepts and skills that are introduced and reinforced. This list includes:

- *Engineering design process*: A series of steps that engineers use to guide their problem-solving. Family Engineering has adopted a simple 5-step version of the design process used by the *Engineering is Elementary (EiE)*[10] curriculum - Ask, Imagine, Plan, Create, Improve.
- *Teamwork*: the ability to function on multidisciplinary teams.
- *Open-ended problem-solving*: the ability to identify, formulate, and solve problems.
- *Communication*: the ability to communicate effectively with others.
- *Societal and environmental impact*: the ability to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
- *Design under constraints*: the ability to design a component, product, or system to meet a desired outcome or solution while accommodating a range of constraints. Constraints may be economic, environmental, social, political, ethical, health and safety, manufacturability, materials, or sustainability-related.
- *Controlled experimentation and testing*: the ability to design and conduct experiments, as well as analyze and interpret data. Understanding of what constitutes a "fair" test.
- *Role of failure*: the recognition that failure plays an important role in the design process and is not necessarily a negative outcome; learning to use failure to find a better solution.
- *Reverse engineering*: the deconstructing, or taking apart, of a product or process to figure out how it works.
- *Systems*: the ability to design systems where many processes must work together.
- *Optimization/trade-offs*: the ability to make trade-offs, or optimize a process, in order to enhance its benefit and minimize negative impacts.

- *Spatial visualization*: the ability to envision 3-D models from 2-D drawings and to "see" how things fit together.
- *Modeling*: the recognition that designs can often be optimized by building models and/or by constructing and testing prototypes prior to building a final product.
- *Properties of materials*: the ability to select the proper material for a given product; recognizing that the properties of a material will determine how that material contributes to a solution.

More than 50 family engineering activities have been developed. These activities fall into two categories: (1) short, self-directed 'opener' activities (2) longer, facilitated engineering challenges. The 'opener' activities are set up before an event so that families can begin working on them as soon as they arrive at an event. A short activity typically takes one to five minutes to complete. It encourages immediate parent/child engagement, and no supervision or facilitation is needed. An easy-to-read sign is placed next to the activity materials, and families work through a simple, hands-on activity that introduces one or two engineering concepts. Materials are easy to reset or replenish for the next family. The signs also include a short engineering connection explaining the basic engineering concept presented.

Longer, facilitated activities are designed to engage families in more in-depth problem- solving and hands-on engineering challenges. They take 20-40 minutes to complete and emphasize parent/child interaction and active engagement. Instructions for facilitators include descriptions of recommended discussion questions, materials distribution strategies, and group facilitation techniques. They may also include extensions, if additional time is available, or take-home ideas to encourage continued family learning and exploration. They include necessary hand-outs or activity sheets, and include a cultural connection and/or fascinating facts about the concept or engineering field featured in the activity.

Family Engineering Events

Family Engineering: An Activity & Event Planning Guide serves as a resource for individuals or organizations wanting to provide informal engineering education opportunities to elementary-aged children and their families through fun and engaging community events. In addition to a collection of hands-on engineering activities, the book provides all the tools necessary to plan, organize and implement a successful Family Engineering event. A number of specific target audiences have been identified as potential event facilitators and users of this resource – professional engineers and engineering societies, student chapters of engineering societies, informal educators, elementary classroom teachers, and parents.

The Family Engineering program has developed a variety of successful, proven event models for implementing a Family Engineering event. A typical Family Engineering event will last 1½ - 2 hours as shown in Table 1 and begins with a variety of short 'opener' activities, engaging experiences set up as table-top stations, available for families to explore at their own pace as participants are arriving. After enjoying the opener activities on their own, families are gathered together as a large group to be welcomed and oriented to the next part of the event. Event facilitators then introduce families to longer activities that allow them to more deeply

explore an engineering concept or field or to experience the engineering design process firsthand through an engineering challenge.

Table 1. Typical Family Engineering Event Schedule.

Time	**Event Activity**
2 hours before event start time	Arrive at venue and set up event
45 minutes before start	Brief event volunteers
Event start time	Families arrive and begin working on opener activities at their own pace
30 minutes after start time	Families brought together to be welcomed to the event and learn about engineering
40 minutes after start time	Families work on engineering challenge activities
90-100 minutes after start time	Wrap up the event
100 minutes after start time	Clean up (takes about 30 minutes)

The longer, facilitated activities last 20-40 minutes each and allow families to work together to solve an engineering challenge or explore an engineering topic in more depth. This portion of the Family Engineering event can be implemented in a variety of formats. Two different formats that have been developed and field-tested are:

- A facilitator leads the entire group, working in family teams, through 2-3 facilitated activities. Volunteers assist with distributing materials and helping families engage in activities.

- Participants split into smaller groups, with participants remaining in their family teams to participate in 2-3 facilitated activities conducted in separate rooms. Families can stay in the same room for multiple activities, or rotate through 2-3 different rooms where different activities are conducted simultaneously during an event.

Following the longer activities, event participants can share some of their learning outcomes and new perspectives on engineering, and be made aware of the *Family Engineering: An Activity & Event Planning Guide* publication, website (www.familyengineering.org), and other Family Engineering related resources available to support their further exploration of engineering. If appropriate, take home materials can be provided to encourage families to continue exploring and learning about engineering together.

A Family Engineering event can also be a wonderful opportunity for participants to meet and interact with professional engineers or engineering students. If any of the facilitators and/or volunteers for an event is a professional engineer or engineering student, some time may be dedicated to introducing them to the group as a role model and having them answer career-related questions from the audience and/or facilitate a Family Engineering activity.

Table 2 provides a sampling of Family Engineering activities, the 'engineering hook' that motivates families to participate, engineering fields introduced through each activity, and the type of activity.

Table 2. Sample Family Engineering Activities.

Name of Activity	**Engineering Hook**	**Engineering Field(s)**	**Type of Activity**
Opener Activities			
Diving Board Dominoes	How far out can you build a cantilever?	Civil Engineering Mechanical Engineering	Hands-on design, building, and testing
Inspired By Nature	What human inventions have been inspired by natural objects?	General Engineering	Object recognition, card matching
Solid Ground	Which earth material makes the best base?	Geological Engineering	Hands-on testing, comparing
Thrill Seekers	Build a roller coaster with turns and loops.	Mechanical Engineering	Hands-on design, building and testing
Engineering Challenges			
Assembly Line	Design a process to minimize assembly time	Industrial Engineering, Manufacturing Engineering	Hands-on design, testing, team collaboration
Blast Off	Design and test an air-launched rocket made from specified materials	Aerospace Engineering	Hands-on design and testing
Give Me a Hand	Design a mechanical device to pick up a selection of different objects	Biomedical Engineering, Mechanical Engineering	Hands-on design and testing

Evaluation and Expert Review

The activities and event formats were field tested February - May of 2010, at eight locations in California, Utah, Michigan, Wisconsin, Mississippi, Georgia, Connecticut, and Puerto Rico. Each site hosted a minimum of five events presented to a broad range of audiences representing different community locations, socio-economic levels, ethnic backgrounds, and facilitation models. Field test coordinators also represented diverse backgrounds in order to test

various volunteer demographics and backgrounds. During the field test period Family Engineering events and activities were conducted by a variety of facilitators – university engineering faculty, STEM college students, classroom teachers, professional engineers, and informal educators. Events were held in elementary schools, science centers, community centers, and corporate settings in order to test a range of locations and facilitation formats and delivery. All Family Engineering activities and instructions are available in English and Spanish language versions and field test sites included facilitation in one or both of these languages, as appropriate to the families participating, in order to eliminate language as a barrier to participation and understanding.

At each of the field test events, evaluative feedback was gathered from participating families, volunteer facilitators, and site coordinators. Results from this formative evaluation were used to guide final development of the activities selected for the Family Engineering publication.

Table 3 summarizes self-reported responses from families attending field test events. While parents often completed the forms if accompanied by younger children, they were asked to discuss each question with their children so their answers would reflect a family perspective.

Table 3. Impacts From Attending Family Engineering Field Test Event. Parents reporting.

Evaluation Questions	**Before attending Family Engineering event we were …**	**After attending Family Engineering event we were …**
Interested in engineering.	3.52	4.53*
Considering engineering as a possible career option for our child/children.	3.45	4.33*
Aware of the connections between engineering and everyday experiences.	3.45	4.59*
Aware of what engineers do.	3.53	4.67*

Change in mean is significant based on a paired sample t-test, p-value <0.05. Average rating based on a scale from 1=strongly disagree, to 5=strongly agree.

Formative data was also collected during field test events on individual activities. Table 4 below summarizes participating parent/family feedback on the short, opener activities. Roughly 3,450 individual ratings contributed to this feedback. The high level of agreement with each of the statements demonstrates the degree to which the openers performed as intended.

Table 4. Short Activity (Opener) Feedback Ratings. Parents reporting.

	% Agreement Across ALL Activities
1. The directions were easy to follow.	96.3% (n=3454)
2. Our family was able to instantly engage in this activity.	95.2% (n=3449)
3. Our family worked together to complete this activity.	91.4% (n=3449)
4. The materials provided were appropriate for the activity.	96.5% (n=3437)

Percent Agreement = Percent reporting 'agree' or 'strongly agree'

Also during the formative evaluation phase of the project, volunteer facilitators from each of the field test sites were asked to comment on the activities they facilitated. This perspective was important to determine if the instructions were clear and the activities were easy to implement and facilitate with families. Table 5 below summarizes some of the feedback provided by these volunteers. Again, high levels of agreement with each of the statements gave the development team confidence that the activities had been written and designed in a way that enabled a broad range of volunteers -engineers, formal and informal educators, and undergraduate students – to implement the activities with ease. The lower rating for ease of clean-up resulted in the development team making some changes to activity set-ups and instructions that improved this factor in future field test events.

Table 5: Long Activity Feedback Ratings. Event facilitators reporting.

	% Agreement Across ALL Activities
1. I was able to explain how this activity is connected to the field of engineering.	95.6% (n=160)
2. I had the right amount of staff/volunteer support for this activity.	89.1% (n=183)
3. I was able to answer the questions families had about the activity.	96.1% (n=182)
4. The written materials provided to me helped prepare me for facilitating the activity.	92.9% (n=183)
5. The activity was easy to set up.	95.1% (n=183)
6. The activity was easy to clean up.	84.1% (n=183)

Percent Agreement = Percent reporting 'agree' or 'strongly agree'.

During the field test phase, a cadre of professional engineers, engineering educators, and experienced formal and informal educators were identified to conduct expert reviews of the Family Engineering draft materials. This review, facilitated by the formative evaluation team, provided expert opinion on the engineering content and educational pedagogy reflected in the

activities being developed. The reviewers' comments informed the refinement of the Family Engineering activities selected for final publication.

Overall, field test results indicated that Family Engineering was meeting the program's goals of enhancing both elementary-aged children and their parents' interest and awareness of engineering and engineering careers.

Inverness Research Associates conducted an external, independent summative evaluation of the Family Engineering program from mid 2011 through early 2012. Event observations and interviews with event participants (children and parents), and event facilitators were conducted. Preliminary findings suggest that families enjoy their experiences with Family Engineering, became more comfortable and confident with engineering as a result of attending a Family Engineering event, and tended to seek out opportunities to explore engineering at home and other settings more frequently than before their exposure to the program. Parents also reported being more likely to encourage their children to consider a potential career in engineering after participating in a Family Engineering event. Summative evaluation analysis was still underway at the time of submission of this paper so only preliminary findings are reported here. A more complete set of findings will be incorporated into the presentation of the paper reported on at the ASEE conference in June 2012.

The Inverness team reported that exit surveys from participating families (n=87) at three Family Engineering events "indicate that families felt the event was of high quality along several dimensions." They asked families to rate their level of agreement with the statements in table 6 below.

Table 6. Exit Survey Responses From Families At Three Family Engineering Events. Parent responses.

Answer Options	1	2	3	4	5
Our family enjoyed the event.	0%	1%	1%	30%	68%
The event encouraged our family to work together.	0%	0%	4%	35%	63%
Our family learned something new during the event.	0%	0%	4%	34%	64%
The event was engaging to everyone in our family, regardless of gender or age.	0%	1%	0%	36%	63%
The event was well organized.	4%	1%	2%	32%	61%
The event introduced us to activities we would do at home as a family.	0%	0%	13%	41%	46%
My ideas about engineers or engineering are different as a result of this event.	0%	4%	23%	39%	35%

Ratings reflect percent agreement with each statement 1=strongly disagree, 5=strongly agree. (n=87)

Summative evaluators also reported that event facilitators found the background information contained in *Family Engineering: An Activity & Event Planning Guide* to be more than

sufficient for effectively planning and hosting an event with 100% of the survey respondents rating the book to be of "high", or "very high" quality. Sample comments from event facilitators appear below:

> *I appreciated the background information at the front of the book. The activities are well organized and the directions are clear. There are a variety of activities. I also appreciate the resources.*
>
> *Actually, I think the entire book is useful – for different reasons. The front of the book helps build understanding and buy-in. The back of the book is the nuts and bolts. I need it all!*

The summative evaluation team also interviewed individuals who had purchased *Family Engineering: An Activity & Event Planning Guide,* but had not yet scheduled their first event. Interviewees felt that "there is plenty of background and supporting information in the book for them to host an event". This was the case regardless of the level of expertise in engineering or education held by the individuals. One book purchaser described to the evaluators that a potential barrier to doing Family Engineering events was the amount of planning and work it could take to get ready. In their opinion, the Family Engineering book did "a great job of making it seem more doable".

Preliminary findings in the summative evaluation phase suggests that from the parents' perspective, attending Family Engineering events made a positive impact on their family's knowledge of and interest in engineering. The events offer experiences that are accessible and fun, and help increase families' understanding of the different types of engineering and what engineers actually do.

In summary, Family Engineering provides an important resource for introducing elementary-age children and their parents to engineering and engaging them together in hands-on experiences that build awareness, appreciation and understanding of the contributions that engineers make to the designed world that we live in. The program also provides professional engineers, engineering students, and educators with proven materials and models for effective community outreach in engineering education. In coming years, Family Engineering will also provide a platform for on-going research on the impacts of early interventions and experiences with engineering as a way to increase the number and diversity of individuals pursuing engineering, and other STEM related careers.

For additional information on the Family Engineering program visit their website at www.familyengineering.org.

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