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Designing *Design Squad*: Developing and Assessing a Children's Television Program about Engineering

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Abstract

This paper describes a multi-media outreach campaign intended to increase children's knowledge of engineering and to improve the public image of the profession. The central element is a reality-based show entitled *Design Squad*, whose first season was broadcast on public television stations beginning in the spring of 2007. The show was developed through iterations of prototype episodes and formative assessment with focus groups. The program features two teams of teenagers competing to solve engineering challenges posed by clients. *Design Squad* highlights the excitement and enjoyment that come from creative technical work. The contestants use modern components including microcontrollers, sensors, and actuators, providing the viewing audience needed exposure to the inner workings of modern technology. The program was broadcast on Public Broadcasting Service television stations nationally. A summative assessment of season #1 was conducted including 139 children who viewed four episodes. The study indicated that the program positively influenced viewers' attitudes about engineering and increased interest in after-school engineering programs. The assessment also suggested that viewers learned about engineering, but they also generalized incorrectly from what they saw. An extensive outreach effort enabled about 30,000 viewers to follow up on their interest in engineering by doing simple design challenges and interacting with knowledgeable adults. Comparison with another reality-based children's educational program entitled *Fetch with Ruff Ruffman* gives insight into how content and format affect outcomes.

Keywords: design education, educational television, project-based learning

Introduction

This paper describes the efforts of WGBH Educational Foundation (a producer of educational materials in many media) and the Massachusetts Institute of Technology to develop a television show and associated multi-media program to engage middle school children in engineering design. A three-year development effort led to full-scale production of four seasons. This paper focuses on the development of the series and the first season. First, we describe the motivation for this effort. Subsequent sections describe the development team and process, the content of the first season, and the assessment of the program's impact.

Motivation

There are two interrelated issues motivating the development of this children's television program about engineering: 1) the persistently inadequate number and diversity of students in the educational pipeline for engineering and 2) the widely held misconceptions about the engineering profession. Here it is argued that television must play an important role in solving these problems.

From 1983 to 2006, science and engineering jobs in the U.S. increased by roughly a factor of two (National Science Board, 2010). During the same period, the enrolment in engineering programs (both graduate and undergraduate) has been nearly constant. The divergence between U.S. demand for engineering talent and the U.S. educational pipeline is depicted in Figure 1. Other nations do not seem to be falling behind rising demand in the same fashion. For example, Science, Technology, Engineering, and Math (STEM) degrees in Asia recently accomplished a factor-of-two increase in a twenty year period (National Science Board, 2006). The divergence between our nation's rising need for engineering and the small U.S. pipeline to the engineering workforce has been characterized by leaders in government, industry, and academia as a serious impending problem for the economy, environment, security, and health in the United States.

A related problem is the persistence of inequities in engineering education. In 2002, only 21% of engineering degrees were awarded to women, and their proportion of the workforce is similar, at 26%, which is about half their representation in the population. Collectively, African Americans, Hispanics, and American Indians/Alaska natives comprise about 10% of the college educated science and engineering workforce even though they represent about 24% of the total U.S. population (National Science Board, 2006).

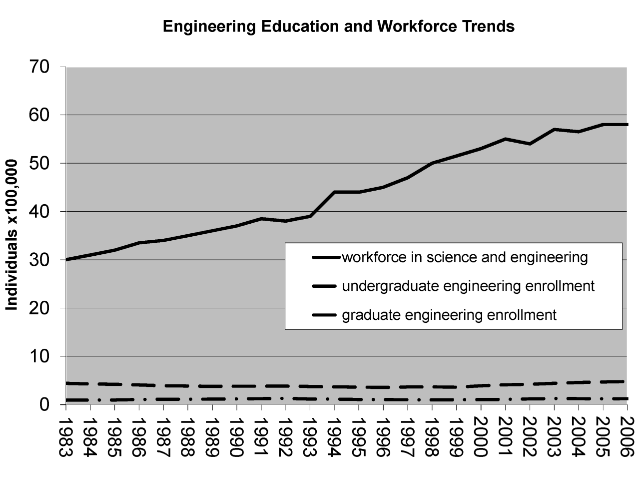

Figure 1. Trends in engineering education and in the size of the technical workforce (National Science Board, 2010).

A contributing factor to these inequities is the public's misunderstanding of what engineers do. To explore this issue, Harris Interactive held telephone interviews with 1,000 adults in the United States. Despite the generally positive image of engineering revealed in the poll, the public was shown to hold significant misconceptions of the profession, and most survey respondents admitted to having little knowledge of engineers and engineering. When asked what comes to mind about engineers, only about 3% of U.S. survey respondents used words like "creative" or "inventive" (Harris Interactive, 2004). By contrast, about 6% of respondents used such words to describe scientists. In addition, engineering is often perceived as inaccessible and engineers are perceived as socially isolated. These perceptions are particularly damaging in recruitment of young women to the field. A study of teenage girls indicates that their most important career motivators include the social atmosphere of the work, the enjoyment of the work itself, and that the work makes a difference in the world (Extraordinary Women Engineers Project, 2005). In reality, engineering may meet all of these criteria quite well, but the perception is that it does not. The Extraordinary Women Engineers Project concluded that, because of the mismatch between public perception of engineering and girls' career motivations, girls generally have decided at a young age that engineering is "not for them."

Given the challenges described above, we argue that popular media has to play a major role in the solution. The majority of the public's information about science and technology currently comes from television and the internet. Television is cited as a source of science and technology information more than twice as often as newspapers and more than ten times as often as either books or family and friends (National Science Foundation, 2001). Because television has such a broad reach and deep influence on our culture, it is a major contributor to the problem and perhaps is also a key to its solution. Recognizing this, the National Academy of Engineering (NAE) called for reform in children's programming:

> Saturday morning television, movies, and other popular media should be strongly pursued to incorporate engineering, math, and science messages. The full resources of the engineering profession…should be brought to bear on this action. (Davis & Gibbin, 2002)

The NAE report was issued in 2002, and since that time there has been an increase in children's programs with messages about engineering. But it is not clear that most of the messages reaching children are the ones the NAE had in mind. For example, in 2005, *The Suite Life of Zack and Cody* premiered on the Disney Channel and for over two years has consistently been among the top ten programs among children aged 9 to 12. This show includes a recurring character, Arwin, who is called an engineer (although he is a maintenance person for a hotel). The character reinforces the most iconic negative stereotypes of engineering: he is socially awkward (wearing glasses taped together in the middle), works in isolation (down in the basement), and has technical skills that cause damage as often as benefit. Because of this and many other images currently featured in popular media, the authors suggest that public perception of engineering generally has not been improving.

The idea of the engineering profession using popular media to influence children's perceptions of engineering has both benefits and risks. Several studies have shown that educational television can support science learning through concept development, improved inquiry skills, and influence on attitudes (Fisch, 2004; Rockman et al., 2007). One significant risk is that popular media may inadvertently contribute to misinformation. As noted by the National Research Council Committee on Learning Science in Informal Environments (2009), "while new media forms make it easier for nonscientists to get access to scientific information … they also provide platforms for unverified information, incorrect explanations, speculative theories, and outright fraudulent claims." So, the quality and precision of the explanations has to be monitored and reviewed by engineers even as the authority over content is in the hands of media professionals. In addition, it is important that new television programs developed for the purpose of advancing engineering as a profession do not merely lead young people to watch *more* television. There is a statistical association (though not necessarily a causal link) between higher amounts of television viewing among children and lower educational achievements as young adults (Hancox et al., 2005). Also, children's TV viewing is statistically and causally associated with obesity (interventions to reduce television viewing among children lead to lower Body Mass Index (Robinson, 1999)). So any new television program runs a risk of primarily expanding the set of viewing options and thereby contributing to two of our worst social problems (declining educational standards and obesity). By contrast, the explicit motivation for *Design Squad* was to promote interest in activities beyond television viewing and so the overall effort included substantial outreach efforts, as described in the section on Outreach Efforts.

The problems described above led WGBH and the Massachusetts Institute of Technology (MIT) to develop a new children's television program entitled *Design Squad*. For more detail on our specific motivation for the new TV program see Frey and Wolsky (2006). For ideas on an even broader engineering outreach to young people, we recommend Sullivan (2006).

The Development Team

The lead organization in developing and producing *Design Squad* was WGBH, Boston's public television station and a producer of educational materials in many media. Some of the television shows produced by WGBH include science programs such as *NOVA*, children's programs such as *ZOOM*, and "how-to" programs such as *This Old House*. For the new children's engineering program, the team at WGBH was led by Brigid Sullivan, Kate Taylor, and Marisa Wolsky. Sullivan is Vice President and Taylor is the Director of Children's Programming at the WGBH Education Foundation. Wolsky was responsible for developing *ZOOM*'s science and math content in close coordination with Science and Math Content Directors, Content Manager, and a working group of advisors. She is also a Producer of *Peep and the Big Wide World,* an animated science series for preschoolers. The Director for the three year prototyping effort was Geoff Adams. A few months prior to filming season #1, the team greatly expanded. Director/Producer Dorothy Dickie joined the team, as did staff for casting, camera, sound, wardrobe, set management, and many others.

The Massachusetts Institute of Technology was a partner in developing content for *Design Squad* seasons #1 and #2. The WGBH team selected Professors David Wallace and Daniel Frey as Series Content Directors for the first season. In this role, they provided technical advice, coordinated development of design challenges, and helped to craft presentation of engineering content in the program. Frey was most active during iterative development and in planning preceding season #1, and Wallace was most active during filming and post-production of seasons #1 and #2. Frey helped the WGBH team to scout locations for filming the program. WGBH chose to film the series on MIT's campus in a garage usually used for the Formula Racing and Solar Car teams. The MIT Edgerton Center manages this space, therefore its faculty and staff played an essential role in the project. Under the supervision of Frey and Wallace, dozens of MIT students joined the team at various times as part of the Undergraduate Research Opportunities Program (UROP), as graduate research assistants, as independent contractors, or as WGBH employees. The MIT students played an essential role in developing prototype design challenges for the program. One of the students, Nate Ball, began in the project as an undergraduate researcher (in UROP) for two years and later, while a graduate student, was cast as a host of the show.

Several other strategic partners have joined the team to augment the effort. These include the American Society of Civil Engineers (ASCE), National Engineers Week, Boys & Girls Clubs of America, Girl Scouts of the USA, National Science Teachers Association, the Society of Women Engineers, Institute of Electrical and Electronic Engineers (IEEE), American Society of Mechanical Engineers (ASMR), and Society of Manufacturing Engineers (SME). WGBH provides these partners with ongoing support, organizes local trainings, and makes introductions among local engineering chapters, public television stations, Boys & Girls Club directors, Girl Scout troop leaders, and classroom teachers. These partners, in turn, bring their first-hand knowledge of the audiences they reach. It is through the combined efforts of WGBH and its strategic partners that after-school engineering activities are coordinated as described in the section on Outreach Efforts.

The team described above is highly diverse in background. The mix of television professionals and engineers and of media experts and academics is not common in our experience. The diversity of the team led to challenges in many cases. The team has a high turnover rate, especially of engineers associated with the show. Multi-disciplinary team coordination is a theme of this paper, both because of its effects on the production and because it is a major theme within the program itself.

Early-Stage Decisions

An important part of developing *Design Squad* was selection of the target audience. The relatively low percentage of students aspiring to math and science careers (less than 10%) and the significantly lower interest among girls as compared to boys (less than one girl for every two boys) are already established by eighth grade (Catsambis, 1994). On the other hand, for an engineering program, it is important that the viewing audience is old enough to comprehend the technical content. The team decided to develop *Design Squad* for viewers aged 9 to 12 (who are typically in middle school). This is an unusual choice for public broadcasting stations, which typically run programming for kids only up to age 8. Reflecting the difficulty of this decision, another program, *Fetch with Ruff Ruffman,* was also developed by one of the team members, Kate Taylor of WGBH. This show is targeted for a younger audience than *Design Squad*, yet addresses some of the same engineering content, although in a simpler way. For example, a major objective of *Design Squad* is to introduce viewers to the design process, as depicted in Figure 2 (WGBH Educational Foundation, 2007a). For comparison, the stated educational philosophy of *Fetch* (WGBH Educational Foundation, 2006) includes the following:

> A major goal of the series is to model for viewers that no matter what the challenge, contestants will need to apply a specific set of skills, which can be performed in different sequences and repeated as necessary, in order to find their solutions. We might think of that model as follows:
>
> - Decide on your goals ...
> - Brainstorm solutions ...
> - Choose your best solution ...
> - Plan it out ...
> - Try it out ...
> - Reflect and rethink ...

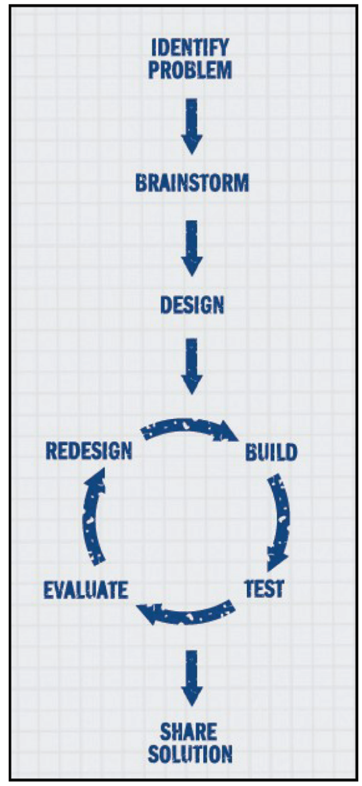

Figure 2. The design process as graphically depicted in the *Design Squad* event guide (WGBH Educational Foundation, 2007a).

Comparing the quote above with Figure 2, one may conclude that the broad objectives of the programs are very similar. Therefore, comparative analysis of *Design Squad* and *Fetch* will be included throughout the rest of this paper.

Another key decision concerns the format of the program. Early in the planning process, the team chose to pursue a reality-based format with contestants persisting throughout a season of the show. An analysis of the viewing data of network television demonstrated that kids in the target age group are primarily watching live-action adult programming. During the early stages of development in 2002 and 2003, among viewers in the target group, 24% of the top 100 network shows and 40% of the top 10 were reality-based. Since this genre had proven so popular for our target audience, WGBH decided to use the same approach to reach kids who would not otherwise tune into an engineering TV show. A reality-based format was also chosen for *Fetch*.

The chosen reality-based format poses some risks. Surveys suggest that reality-based shows depend for their appeal substantially on the belief that they are *realistic*, at least to some degree (Papacharissi & Mendelson, 2007). At the same time, viewers also tune in because they find the events amusing, exciting, and entertaining. One risk is that reality-based shows influence the events depicted (for entertainment value), yet present them in such a way that the differences from reality are not salient. For example, most viewers do not notice that the production credits for many reality-based programs include "story editors." This may cause viewers to have incorrect expectations when they encounter events in real life that are similar to those depicted in reality-based shows. A responsibility falls upon producers of reality-based programs, especially those made for children, to handle these competing factors in a responsible manner.

A related issue specific to *engineering* reality programs is what sort of challenges are possible to undertake within the limits of the production schedule and with contestants who lack much formal engineering-related education. Exploring this issue was a major goal of an NSF planning grant (WGBH Educational Foundation, 2002). Under this grant, WGBH undertook a series of one-day design/build exercises. For each exercise, we gathered a group of adults without engineering degrees (mostly WGBH staff). We gave them a design challenge to accomplish with materials and tools available from local hardware stores. For example, in one exercise, the team built a one-passenger hovercraft using a leaf blower, foam insulation, plywood, and plastic sheets. These exercises helped the WGBH team build confidence and "work out logistic and production questions" related to challenges on the proposed scale (WGBH Educational Foundation, 2002). The WGBH team had considerable experience from *ZOOM* in developing challenges at a length scale of a few inches and with power on the order of a few Watts. The exercises conducted under the planning grant gave the team experience with challenges at a length scale of a few feet and with power on the order of a kilowatt.

The demographic profile of the contestants was another key early-stage decision. An important goal of casting contestants was to provide role models for girls and minorities. Previous experience from *ZOOM* was helpful in this regard, since this show had attained good ratings in minority households. It was decided that *Design Squad* would feature contestants from a range of racial, ethnic, and socio-economic backgrounds, and have equal numbers of boys and girls. It was hoped that, when viewers watched, they would see kids with whom they could identify. Previous experience from ZOOM also established that an age difference between the audience and cast can draw upon the remarkable way kids tend to emulate and imitate slightly older kids. It is also helpful that the slightly older contestants have a greater capacity to acquire the skills and content knowledge needed for the engineering challenges posed on the program. The exact number of the age difference for *Design Squad* was established in the formative assessment process, including a sequence of prototype episodes. The next section describes the sequence of prototypes and how they were studied to inform the development of *Design Squad*.

The early-stage decisions were greatly influenced by the competitive landscape, which was changing rapidly throughout the development process. In the fall of 2002, *Operation Junkyard* premiered on Discovery Kids' NBC Saturday morning block. *Operation Junkyard* was based on the popular program *Junkyard Wars* (originally a BBC program which was also re-versioned for U.S. audiences by The Learning Channel), but was targeted for a younger audience. It featured teams of children faced with challenges such as making catapults, water bikes, etc. (Corus Entertainment, 2006) This show never earned high ratings and, even though it earned a daytime Emmy nomination for Best Children's Series, it only lasted one season of 13 episodes. WGBH decided to differentiate *Design Squad* from *Operation Junkyard* along various dimensions, such as placing much greater emphasis on the educational mission of the program and featuring more modern technologies in the solutions. In the fall of 2004, *Project Runway* premiered on the cable station Bravo. *Project Runway* features individual designers competing in a sequence of challenges, such as making a gown with materials available only at a supermarket or making a new uniform for postal workers (suited to either spring or winter weather conditions) (NBC Universal, 2007). Although the focus is on aesthetics primarily, the program features substantial technical deliberations regarding construction of garments, materials, budgets, and schedules. This design-related reality-based show is a ratings hit with over 3 million viewers per episode on average in its third season and it already spawned a successful spin off. *Project Runway* has had a large effect on the thinking behind *Design Squad*, most obviously in episode #8, "Functional Fashion."

Iterative Prototyping and Formative Assessment

Based on the progress under the planning grant from NSF, WGBH was awarded a development grant (WGBH Educational Foundation, 2004). This funding from Informal Science Education supported a sequence of three prototype episodes which were filmed and edited from 2003 to 2005. The prototype episodes were subject to formative assessment. For the first two prototype episodes, focus group methodology was used to elicit feedback from viewers in the target demographics. The Michael Cohen Group organized viewing sessions with children in groups of three to five people in each session. Observations were made as the children were viewing and detailed discussions with the children were conducted afterward. Dozens of such focus groups were conducted in Cambridge Massachusetts and Stamford Connecticut and so that, in total, over 100 children viewed each of the first two prototype episodes. The prototype episodes and the focus group results were then reviewed with a panel of advisors including experts in children's education, engineering, and science.

The first prototype episode, entitled *Lazybones*, was filmed in 2003. The concept of *Lazybones* was that the teams would automate everyday tasks for the two hosts. One host was a wise-cracking improvisational comedian, the other was a "straight man" in the comedic scenario with a strong technical background. Eight contestants were cast—in this prototype episode it was a mix of high school and young college students. The challenge posed was to build a machine that can cook scrambled eggs at the push of a button. Finding ways to crack an egg without entraining shell in the mixture was a key element of the challenge. In *Lazybones*, "failure points" were used to encourage the teams to explore lots of ideas early. Any ideas that failed, but provided key lessons to the team, netted the group bonus points. This "failure point" concept was intended as a way to teach viewers about the engineering process. This is important as research on children's educational television has shown that science process is one of the lessons that can be effectively transmitted via television (Fisch, 2004).

In the *Lazybones* episode, the points were awarded to the team that broke the egg between two bricks and quickly discovered that separating the shell afterwards was too difficult. The same team later chose a concept using a tube to guide an egg as it fell onto a blade, cracking its shell (see Figure 3). At one point, the team faced a decision concerning whether to arrange a tube in their machine vertically or at an angle. Animation illustrated the effect of the tube's angle on the performance of the machine. This introduced terms like "potential energy" and "friction" to be illustrated in the context of technical decision making. The other team employed servo motors to drive the motions of a spatula. This provided an opportunity to explain the functions of servo motors and also the use of linkages to convert rotary motion into linear motion. The WGBH team established that filming young people doing design work for two days would provide enough material for a half-hour educational television program.

The focus group evaluations of *Lazybones* indicated the show strongly appealed to kids of both genders across all the ages sampled (Michael Cohen Group, 2003). Overall, the research participants were extremely engaged in the program, exhibiting enthusiasm while viewing and during discussion afterward. They showed high interest and formed opinions about the engineering designs, making comments such as "I think they should have stayed with the brick idea." Participants admired the skill and teamwork of the contestants making comments such as "Erin was really, really good and really smart. She made the spatula." and "George came up with the plans—he figured out how to test the height for dropping the egg." The idea of meeting challenges that would "make things easier" resonated strongly with the participants. Focus groups also suggested that participants understood the scientific/technical concepts presented. For example, viewers remembered how the servomotor was used and that its motions were programmed using a computer. In addition, children were able to articulate different parts of the engineering design process.

Despite the generally positive results, the focus groups revealed some opportunities for improvement. In this prototype film, players were aged 17–20. Focus groups reacted negatively to this, making comments such as "it should be kids like 15 or younger—not in college"

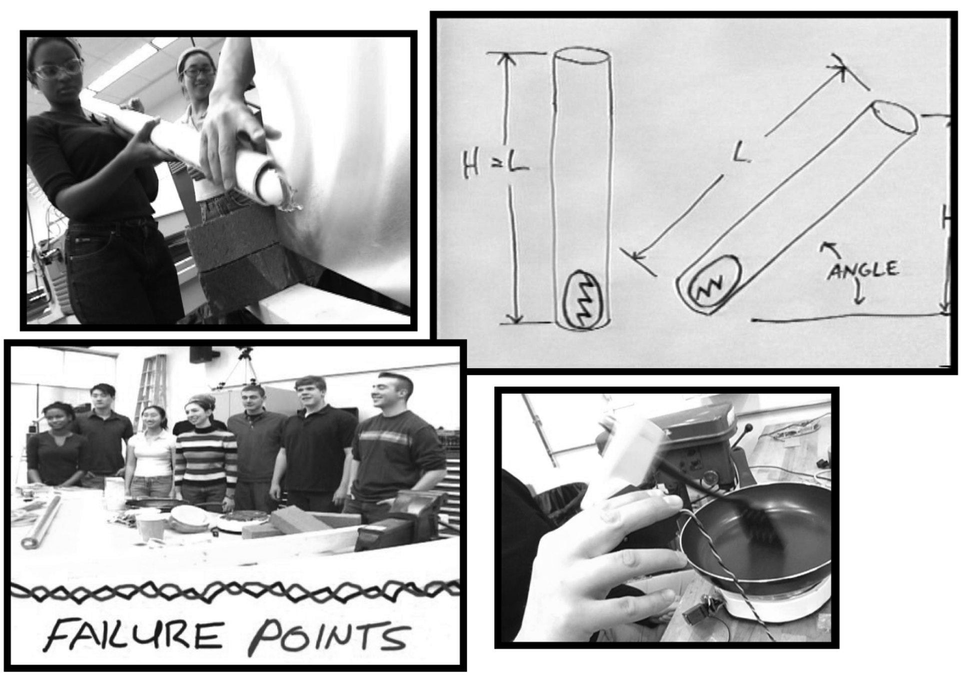

Figure 3. Screen shots from the first prototype episode that was filmed in 2003. In this episode, two teams built machines that made scrambled eggs at the press of a button.

(Michael Cohen Group, 2003). Also, viewers suggested that they would prefer more fun and whimsical challenges. The viewers also suggested that competitive aspects of the show should be emphasized, including rivalry between the teams and a clearer depiction of what the winning team would gain. *Lazybones* was filmed at Olin College of Engineering in an area where the two teams could build in entirely separate spaces, with the hosts observing through large windows from a room in between. The feedback suggested that much more contact between the two teams would heighten viewer interest.

After WGBH filmed the *Lazybones* prototype, they began to pursue another path in addition to the concept that eventually led to *Design Squad*. WGBH began pre-production of *Fetch with Ruff Ruffman,* which was designed to appeal to a slightly younger (but overlapping) audience (aged 6–10) and, therefore, featured an animated dog host whose name is in the show's title. The humorous and eccentric animated dog presents the challenges to the live action contestants and (in the second season) plays off a non-speaking character (in the tradition of Harpo Marx or Raymond Teller), an animated cat named Blossom. Season #1 was in pre-production in 2004, filmed in 2005 and premiered in May 2006, and season #2 followed a similar schedule one year later.

At the same time, WGBH continued development of the show intended for an older audience. In 2004, feedback from the *Lazybones* focus groups was used in the production of a second prototype episode. WGBH chose the title *Design Squad* at this stage. This second prototype cast younger players, ages 14–18 rather than 17–20. WGBH chose a challenge that had tested well with the focus groups, a water-balloon filling machine, and also tried a different story line for the adult characters to structure the show. In this episode, a female character is chief engineer and all-around boss at a new company that designs whimsical machines to solve its clients' problems. Her employees, acted by improvisational comedians, each mentored one of the two teams. The filming all took place in a single floor of an unfinished building with few interior walls, which promoted a greater degree of interaction between the two teams.

Children in the second round of focus groups found the concept of the show compelling and appropriate to their age group and interests (Michael Cohen Group, 2004). They enjoyed the focus on problem solving, teamwork, and competition. The more whimsical challenge garnered positive reactions. The water balloon theme also led to very popular moments of physical humor. The viewers also frequently retained ideas about engineering phenomena (e.g. when water flows through a network, it tends to follow the "path of least resistance") and formed opinions about preferred techniques for sealing joints. Despite generally positive reactions, some new weaknesses were revealed. The fictional premise of the prototype episode did not test well. The viewers also wanted more detail in some technical areas, especially what components were being used and where they came from.

A brief aside is warranted here on an interesting aspect of formative assessment of the second prototype episode. The children in the focus groups generally felt that the name of the show, *Design Squad*, did not fit, and specifically objected to the word "design" being used in an engineering show. Some kids indicated that they associated "design" with home interior decoration rather than invention or technology. This particular drift of the word "design" away from engineering may continue as the reality show *Top Design* (featuring interior decoration, not engineering) premiered in 2007 on the cable station Bravo and has earned high ratings. This is another sign of subtle effects that popular media can have on public understanding of engineering. The term "design" has long been recognized as being at the core of the engineering profession and also at the center of disputes over uses of words related to our profession (Baddour et al., 1961). Today the risk is especially high that the word "design" will become dissociated from engineering in the public's perception, and it is worth considering if and how our profession can reclaim the word.

Based on the previous two rounds of formative assessment, a third prototype episode was filmed in the summer of 2005. WGBH tried a different title of the show, *Gizmo*, because it tested well with audiences. The most significant change to be tested in *Gizmo* was the addition of shopping trips (which are a successful feature of reality based design show *Project Runway*). Rather than having kits only, the teams would have a budget and time to go buy things they want or need to execute their design concepts. It was felt this new element of the show would be a natural way to include descriptions of the materials and components while avoiding a "kit inventory" process which might lose the interest of viewers. Another significant change was that the fictional elements of the show were dropped entirely. The two hosts in *Gizmo*, a man and a woman, were young adults with technical (not comedy) backgrounds that monitored the team's progress and provided occasional guidance. Having no need to introduce or sustain a fictional scenario opened up time for the shopping trips and for more technical content and allowed for a "real-world" client to introduce the challenge. The engineering challenge in *Gizmo* was to design and build a machine to make peanut butter and jelly sandwiches. This challenge proved to be very difficult, especially in light of the time for shopping—the logistics of shooting off-set absorbed a large fraction of the two-day shoot. The actual machines produced by the teams in this third version were probably the least reliable and least fully complete of those developed in all three prototype episodes. Automatically manipulating peanut butter and bread is deceptively difficult. This served as important guidance regarding the complexity of challenges and its influence on the amount of time, training, and assistance required by the teams.

The third prototype was not subject to focus group testing because full-scale production of *Design Squad* season #1 began soon thereafter (copyrights held by another broadcaster prompted WGBH to revert from *Gizmo* back to *Design Squad* as the final choice of title). Even though we lacked formal feedback from viewers, many elements of *Gizmo* were retained as elements in full scale production, including the set location at MIT, dropping the fictional elements, the shopping trips (in most episodes of season #1), and one of the hosts (an MIT graduate student, Nate Ball).

6. The First Season and Associated Website

This section describes the first season of Design Squad and its associated website (WGBH Educational Foundation, 2007b). The first season was comprised of 13 episodes spanning mechanical, civil, electrical, computer and other engineering disciplines. The entire first season is available via streaming video at the website (WGBH Educational Foundation, 2007b). All the episodes of the first season featured a single cohort of eight youngsters reappearing each week (upper panel of Figure 4). The contestants, Michael, Noah, Kim, Krishana, Giselle, Tom, Natasha, and Joey are all featured on the website, which enables viewers to learn more about their favorite contestants. For example, Krishana's views on engineering and the need for creativity and persistence in the face of failure are featured on the site (lower panel of Figure 4). The composition of the two teams competing in challenges varied week to week so that different interpersonal interactions play out in each episode. In addition, this format ensured that each participant had a good chance of experiencing a range of outcomes including technical successes and failures. Having recurring players throughout a season also enabled the viewing audience to see that, with practice, the contestants improved their skills over the course of the season. Four of the episodes are described below in the order in which they were completed and broadcast. These are the same four episodes that were subject to summative evaluation as will be described in the next section.

Episode 1—"The Need for Speed": The client for this episode was Dan Page, a race car designer who posed the challenge to the team of developing a vehicle to be raced at the New England speedway. At the beginning of the episode, it was revealed that the teams must build their dragster by modifying a child's riding toy using two cordless electric drills as the source of motive power. The teams flip coins to determine which they will modify—a tricycle or a wagon. The blue team (Krishana, Noah, Kim, and Tom) earned first choice and selected the wagon. The red team (Natasha, Joey, Giselle, and Michael) had to use the tricycle and decided early on to use a direct-drive approach with two drill drivers attached to the single front wheel. This simple approach enabled them to have the first successful test drive. Blue team recognized that the red team vehicle was fast and that they would need some unique advantage in their design to have a chance at winning. They began to develop a simple sort of continuously-variable transmission (CVT) system made

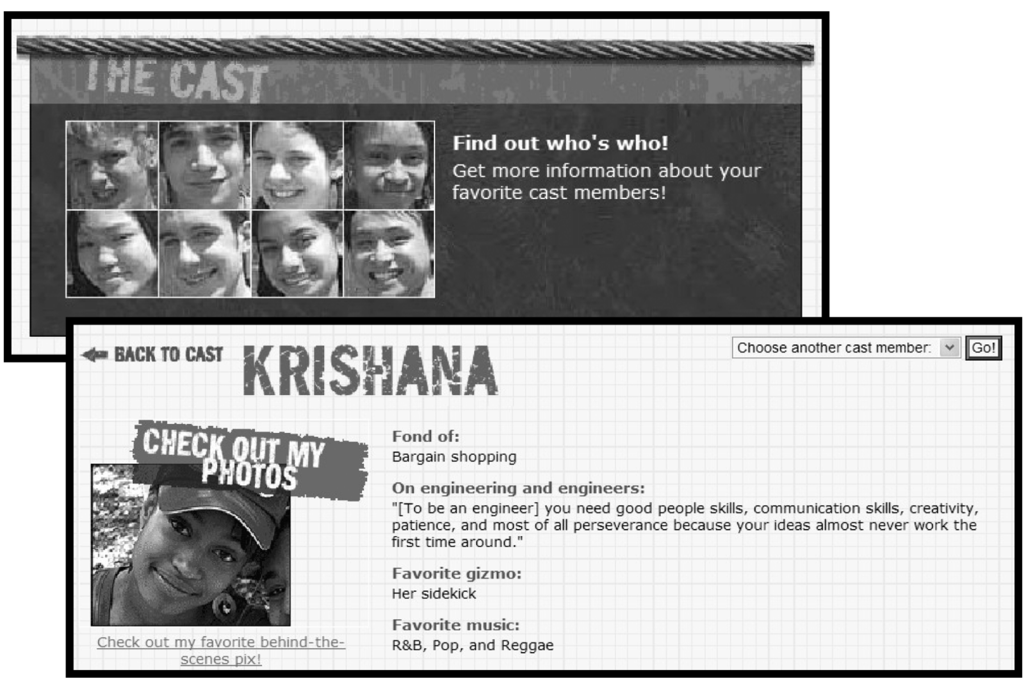

Figure 4. The contestants in *Design Squad* Season #1 as featured on the *Design Squad* website (WGBH Educational Foundation, 2007b).

with two spools and cable or rope. In the episode and on the website, an animation of the system (by David Wallace and Geoff Adams) with voice-over narration (by Nate Ball) illustrated how this system provided high torque at the starting line and high speed near the finish line (on the left in Figure 5). In the finale at New England Speedway, the blue team and its CVT were overtaking red team and seemed likely to win when their transmission tangled and jammed. The red team and their simpler direct-drive system crossed the finish line alone (center of Figure 5) and won the week's competition. Additional details on the reasons for Blue team's breakdown in the race are provided on the website (WGBH Education Foundation, 2007b). Also on the website are plans for an at-home design project—a rubber-band-powered dragster with CDs for wheels (on the right in Figure 5).

Episode 2—"Rock On": A rock band formed by four MIT graduate students posed a challenge to the *Design Squad* contestants—make new and unusual musical instruments, one stringed (and able to play a full octave), the other percussion. Blue team, as their stringed instrument, designed and built a small electronically-amplified harp made from bent pipe, guitar strings, and pick-ups. The team called their invention a pipe harp or "parp" (upper left in Fig 6). Red team attempted a large stringed instrument made in the form of two parallel discs between which the strings are tensioned. With all the strings the same length, the range of notes must be attained entirely by string diameter and tension. The red team named their instrument "string-henge" in reference to its large dimensions and as an homage to the movie *Spinal Tap*. Both teams also made percussion instruments reminiscent of those used by the *Blue Man Group*. In the finale, the band played the winner's (Blue team's) instruments in a concert for a live audience. The website associated with "Rock On" includes a video game developed by WGBH web designer David Peth (WGBH Educational Foundation, 2007b). The game and associated animations and explanations (by Daniel Frey and David Peth) are meant to reinforce key concepts from the episode, including wavelength, acceleration, force, and equilibrium. These physical concepts are related to the events in the episode and the music made in the game. The website explains the influence of design parameters on the performance of stringed instruments (Fig. 6).

Episode 3—"Skunk'd": The client for this episode was a club in Cambridge, MA, named "Subversive Choppers Urban League," that builds and rides unusual bicycles. Red Team decided to make a two-person back-to-back bike (left side of Figure 7) (WGBH Educational Foundation, 2007b). To do this, they locked the handlebars of the backwards-facing rider, so only the front rider could steer. Meanwhile, the backwards-facing rider was responsible for pedalling. This brought about some interesting discussions among team members of design and biomechanics, since the drivetrain in this configuration requires the rider to pedal backwards to make the bike go forward. Blue Team also designed their bike for multiple riders, but they chose to have them all face forward and sit side by side (center of Figure 7). The website gives access to more discussion of the design issues involved, such as the safety concerns arising from two riders both manipulating the same steering wheel. The site also links the content to the professional world of engineering via an interview with Kevin Tisue, owner of a company called Next Dimension Engineering

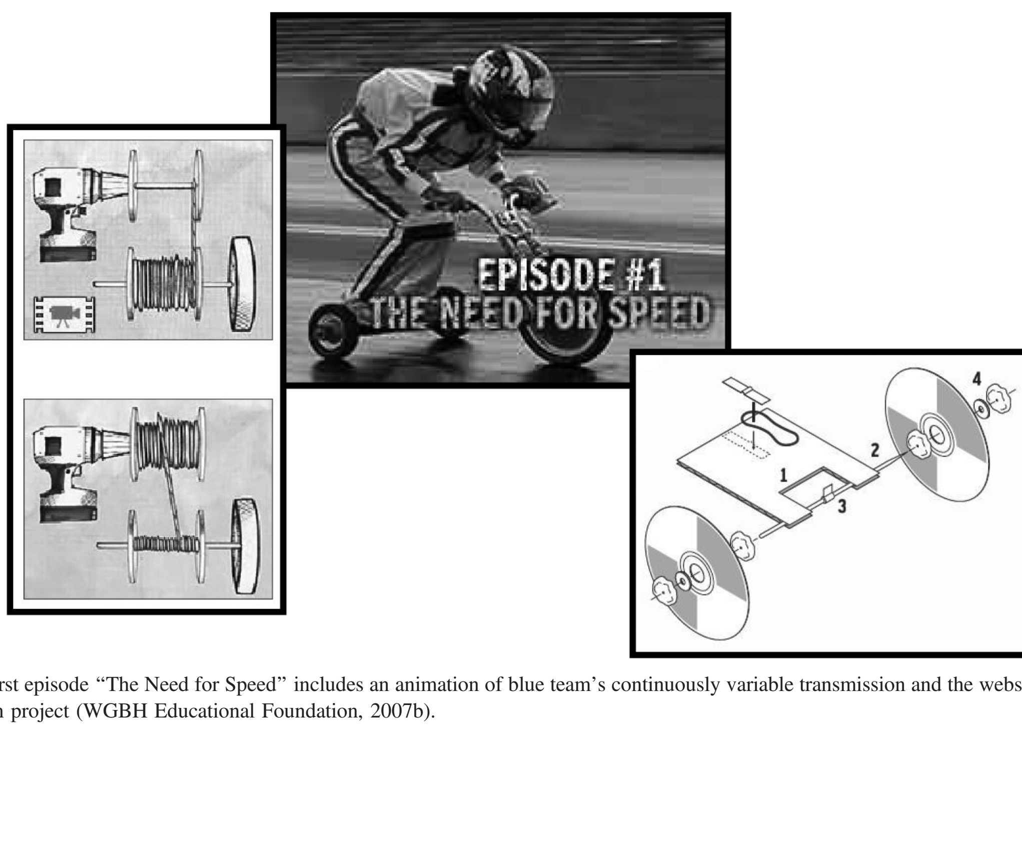

Figure 5. The first episode "The Need for Speed" includes an animation of blue team's continuously variable transmission and the website has plans for a hands-on design project (WGBH Educational Foundation, 2007b).

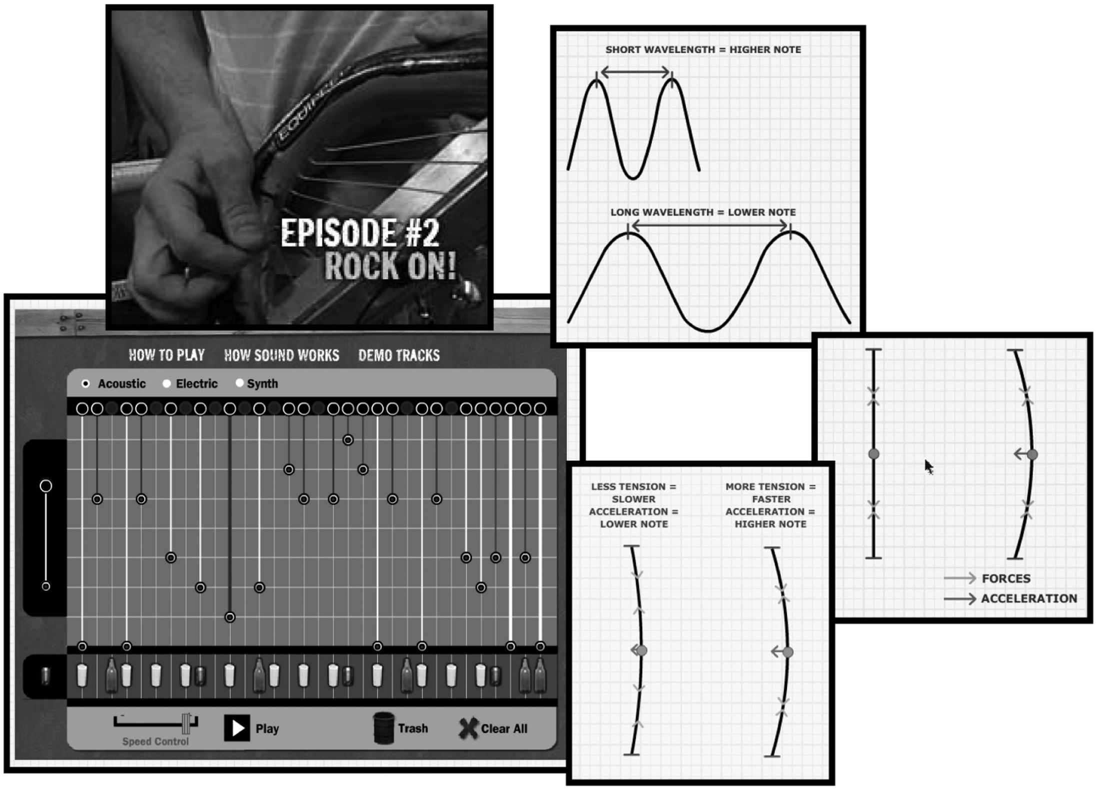

Figure 6. In the second episode "Rock On" teams developed musical instruments. The associated website includes a game, animations, and explanations meant to reinforce key concepts from the episode (WGBH Educational Foundation, 2007b).

that designs parts for bicycles and other equipment of interest to our viewing audience like snowboards (right side of Figure 7).

Episode 5—"Got Game?": The client for this episode was a local school that requested systems to film their basketball practices (on the left in Figure 8). Blue Team was tasked with making a system to film at ground-level while Red Team was required to film the practice from above. Red team chose to suspend their camera by cables attached to support structures above the basketball hoops. This decision influenced the requirements in designing the gimbal system to point the camera. Two team members, Mike and Kim, each designed a solution (in the center in Figure 8). Mike involved other team members in the process while Kim executed her design more individually. The team chose Mike's design since more people felt ownership of this option. Unfortunately, this decision contributed to Blue team losing the challenge. As explained by animations, Mike's design placed the center of mass far from the center of rotation causing the gimbal and suspension cables to swing. The website provides some discussion of the decision-making process and offers

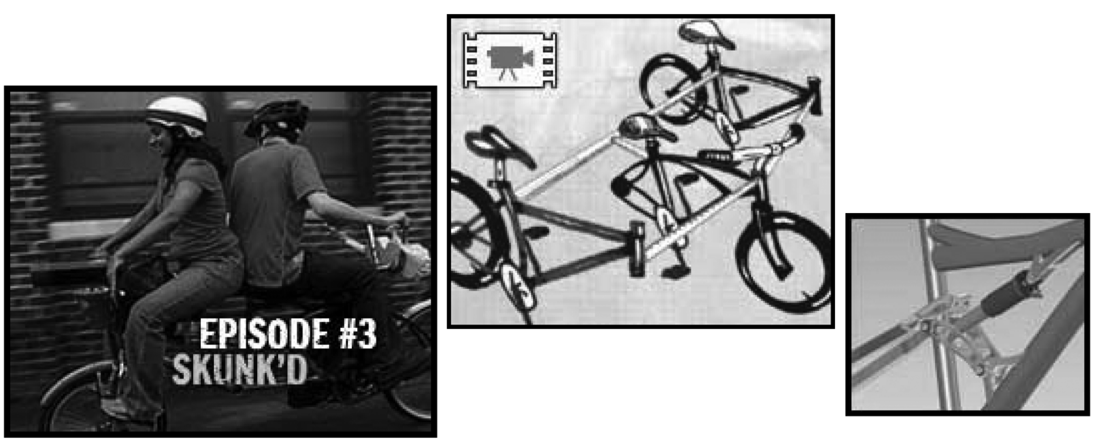

Figure 7. In Episode #3, "Skunked," the contestants built unusual bicycles and the website includes an animation of both bikes and an interview with a professional engineer who designed a linkage for a seat post (right) (WGBH Educational Foundation, 2007b).

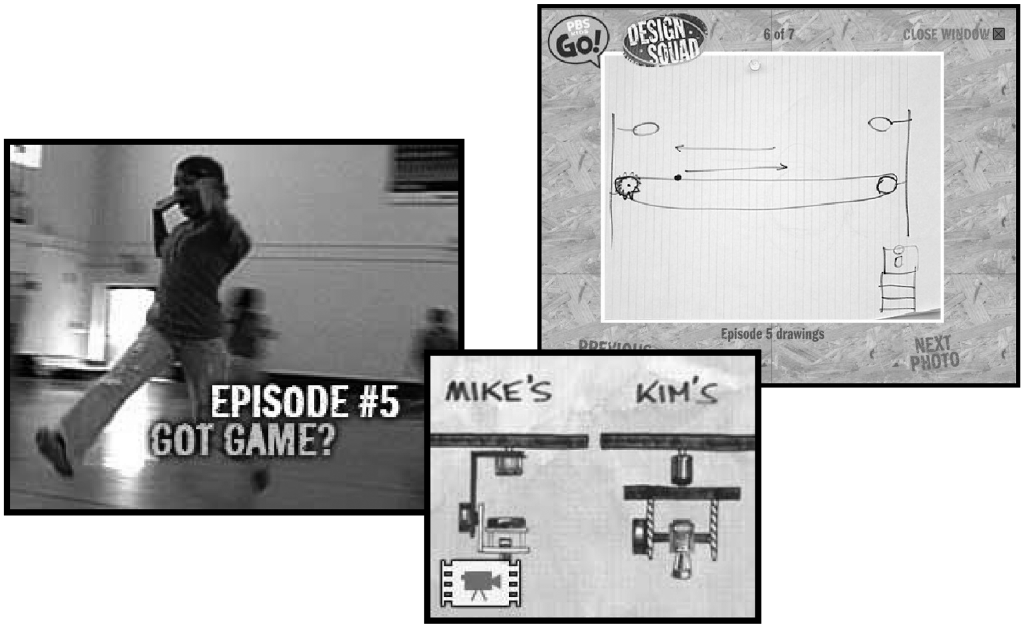

Figure 8. In Episode #5, "Got Game?", the contestants built systems to film basketball practice for a local school and red team suspended a camera overhead on a cable, leading to a choice between Mike's and Kim's designs for a gimbal system to control its viewing angle (WGBH Educational Foundation, 2007b).

suggestions about how the team might have deliberated more effectively (WGBH Educational Foundation, 2007b). Also available on the website are sketches the team made during their deliberations (on the right in Figure 8).

The four episodes described above share a few notable properties that are also generally present in the other nine episodes of the first season: 1) the challenges are fairly complex and often have multiple sub-systems to be executed and integrated (e.g. steering and drive-train), 2) the contestants made use of technology not available in most homes (welding, radio control electronics, etc), and 3) they describe some events in the design process using analytical thought processes familiar to engineers but not to the general public.

As a basis of comparison, consider the content and format of *Fetch with Ruff Ruffman* season #2. In every episode, two pairs of contestants (aged 9 to 12) were sent out to tackle challenges. One pair generally addressed a topic related to science and engineering. For example, in episode #3 "You Lucky Dog," which aired in 2007, the challenge was to build a soap box racer (WGBH Educational Foundation, 2007c). The other pair addressed a topic related to culture (art, sports, etc.). In "You Lucky Dog," the children participate in Chinese New Year festivities, including dragon boat racing and sampling traditional Chinese foods. In the engineering challenge, the kids were shown brainstorming concepts for their vehicle on paper. The children also participated in the building, but the assistance of adults is more extensive and is clearly evident in the episode. A test of the vehicle demonstrated a difficulty—braking was shown to cause an undesired turn to the left. A simple animation illustrated the physical effects. Corrective design changes were discussed and implemented. A finale race was held, but it was between the *Fetch* contestants and an outside adversary, not another contestant. Ruff, the wise-cracking animated dog host, assigned points to the teams based on his observations of the events that took place. Also, there was a "half-time quiz," and contestants in the studio answered questions about what happened in the challenges out in the real world.

The key distinctions between *Design Squad* and *Fetch* are the level of engineering content and the percentage of the show dedicated to it. *Design Squad* is presenting quite advanced technical content and is essentially all about engineering. Given the target age group of 9 to 12 year-olds, the material in the show is demanding of the audience's concentration and background. *Fetch* is presenting much simpler challenges, using less advanced components and fabrication techniques, and employing simpler explanations in its broadcasts and in its supporting web media. The different treatment of engineering subjects and the lighter style (e.g. the cartoon host) are meant to appeal to its slightly younger target age group of 6 to 10 year-olds. *Fetch* is also more varied in its content, with a mix of cultural, scientific, and engineering content. However, the theme of using a creative process to address challenges and to learn from experimentation is a common thread through most every episode. The following section reviews summative evaluation of *Design Squad* with some comparisons with *Fetch* to illustrate the ways that content and style affect outcomes.

As discussed earlier, using a reality-based format creates some responsibility for the producers to represent the events that transpired with some degree of fidelity. In *Design Squad*, a number of episodes required intervention to attain an outcome that would work as television. For example, in "The Need for Speed" the producers felt that both Blue and Red team's vehicles needed to be fully functional for the finale. Near the end of the last day of shooting, Blue team damaged their vehicle in a test (the axle broke). Between the last day and the finale, the engineering support personnel completed repairs of the vehicle and also made some modifications to avoid another breakdown too early in the race. The episode clearly showed the breakdown after the test run and also presented discussion by the contestants of what repairs were needed. But the shooting schedule and union rules for the contestants precluded their completing the repairs themselves as a viewer might assume they did. Another example is an episode "Collective Collaboration" in which the teams made human-powered peanut butter makers. In the finale, the winning team's prototype design made some peanut butter (but not much). A more rugged machine was fabricated in the U.S. for the client in Haiti based on the prototype design made by the contestants. The new machine could not make any peanut butter at all. During filming in Haiti, some peanut butter was added to the input along with the peanuts to make the machine work. This was probably the biggest deviation between reality and reality-based television that was allowed to occur in season #1. As a consequence of such events, *Design Squad*, runs some risk of making engineering appear simpler than it really is. In the TV program, working solutions emerge reliably from two days-worth of team effort by teenagers. In reality, things go wrong more often than was depicted in the final, edited versions of the episodes. Part of this issue is driven by the technical complexity of the projects featured in *Design Squad* which we feel make the show more exciting. *Design Squad* is seeking a delicate balance between fully realistic outcomes and more inspiring outcomes.

By comparison, *Fetch* uses less advanced technical projects and presents more explicit adult participation. The projects *Fetch* presents are more like the projects kids commonly do with adults such as those featured in *The Dangerous Book for Boys* (Iggulden & Iggulden, 2007) and *The Daring Book for Girls* (Buchanan & Peskowitz, 2007). These two books, which together have sold more than 4 million copies in the U.S., show kids how to make a battery, build a bow and arrow, and estimate the earth's circumference. In a similar vein, *Fetch* challenges the kids to design a paddle boat, build a shelter in the woods, and use a compass. A potential advantage of such challenges is that kids will more likely be able to reproduce the outcomes on the show with their parents. A potential downside of these simpler challenges is that they may seem less exciting to the viewers. Suggesting a degree of mutual influence between the shows, the second season of *Design Squad* has included some challenges more amenable to replication in the home, such as a challenge to build a kayak from PVC pipes, tie wraps, and plastic sheets.

The format of the show, the types of challenges, and the balance between technical subjects and reality-based drama seems to have appealed to media professionals. Perhaps the strongest evidence is that Design Squad earned a George Foster Peabody Award in 2007 (University of Georgia, Grady College of Journalism and Mass Communication, 2007). The reasons for the high regard for the show are suggested by the following comments from media professionals:

> …As a science primer, "Design Squad" succeeds swimmingly, walking kids through the process of conception and design, and using animation and voice-over narration to explain the trickier ideas. ... The 20-something hosts, Nate Ball and Deanne Bell, ... happen to have serious engineering backgrounds and keen advice. Likewise, the teens are sharp and opinionated, and their conflicts could tell stories of their own. At one point, Krishana and Giselle, two girls who can hold their own with a bandsaw, grumble that the boys on their team aren't taking their ideas seriously. ...We'd likely find some enlightening lessons there, too.
> — *The Boston Globe* (Weiss, 2007)

> ...The groups rely on collaboration and teamwork to design and create solutions to various engineering challenges, and they're always respectful of each other's ideas and willing to discuss lots of possible scenarios. What sets this series apart from other reality shows is the teens' positive attitude— they don't get upset over losses, instead celebrating (and congratulating) their peers' ingenuity. Tweens with the building bug will love this smart series— and with four girls in the cast, viewers will be reminded that engineering isn't just a guy thing anymore.
> — Common Sense Media (2007)

> Design Squad is a true delight—educational television in the best sense of the term. This series … works because it recognizes and appreciates the intelligence of its intended audience. It also engages that audience, drawing on their knowledge, and love, of reality television contests… But here they can also appreciate the intellectual and physical challenges involved as their peers struggle to figure out how to build a drag racer from a tricycle… They learn teamwork as they watch groups brainstorm, design and test, fail, redesign, build and compete. Add to this clear commentary and outstanding graphic illustrations of what the kids are learning as they work…,
> — University of Georgia, Grady College of Journalism and Mass Communication (2007)

Summative Evaluation

The first season of *Design Squad* was subject to summative evaluation conducted by Goodman Research

Group (GRG). Eight classrooms with a total of 139 fifth and sixth grade students were recruited by GRG in California and Massachusetts. The average age of students in the sample was 11, just over half were female, 17% were Hispanic, 15% were African American, and 9% were of Asian descent. These 139 students watched the four episodes described above. One week before viewing and again one week after viewing the set of episodes a survey was administered to each child individually. There are additional details on the research methodology including the pre- and post- survey instruments in the final report by Goodman Research Group (2007) to WGBH Educational Foundation.

The survey results related to attitudes about engineering are summarized in Table 1. The vast majority of response means were affected in the direction we regard as preferable. Five of the changes pass a Students' t-test for significance at $\alpha=0.05$ (note that with this many test items, one of those could be a false positive with moderately high probability). The two largest changes related to the statements "Engineers solve problems that effect real people" and "Engineering is boring." These changes in attitude are unambiguously improvements. The statement "only geniuses can succeed at engineering" moved in the direction of greater agreement, but not with high certainty (the change does not pass a test of significance at $\alpha=0.05$). Our interpretation is that viewing the four episodes probably gave some children the impression that engineering is somewhat harder than they previously thought it was. In the view of the authors, this outcome might actually be helpful if it adjusts the viewer's perceptions to be closer to reality before they actually try an after-school engineering program. Especially in light of the concerns about the reality format and the engineering interventions required, both discussed earlier, we see this trend as positive.

Although the attitude changes due to *Design Squad* are generally in the right direction, and some have been demonstrated to be statistically significant, it is worth saying that none of the effects are as large as we hoped to see. The largest changes in attitude we observed were about 0.5 on a 5 point scale. Programs intended to change attitudes toward science often demonstrate effects above 1.5 on a 5 point scale (e.g. Norby, 2003). Furthermore, the links between changes in attitudes, especially ones measured in the short-term, and changes in behavior are often weak. If the goal of *Design Squad* is to actually influence enrolments in engineering programs in the future, we need to seek other indicators as well, and probably need to conduct a longitudinal assessment on the time scale of several years with a smaller group of viewers. It is also imperative that sufficient opportunities exist so that the increase in student interest in after-school engineering activities can be translated into action. WGBH outreach efforts along these lines are described later.

It is instructive to compare the attitude changes due to viewing *Design Squad* to those observed due to viewing *Fetch*. GRG conducted pre- and post- surveys of 168 fourth grade students who viewed five episodes of *Fetch* season #2. Note that season #2 of *Fetch* aired during the same general time frame as season #1 of *Design Squad*. The five episodes included challenges such as a swimming race between a kid and a dolphin (focusing on characteristics of mammals and how dolphins are adapted well for water), designing of a soap box racer (focusing on steering, braking, and drag), determining the effectiveness of dogs in relieving stress of medical patients (focusing on design of experiments), designing of a device to bowl a strike every time (focusing on impact and momentum), and using a fMRI (functional Magnetic Resonance Imaging) machine to determine if people really do use only 10% of their brains. The viewers were one or two grade levels younger than the *Design Squad* viewers. The study participants were asked to indicate their agreement with statements "I like science," "I enjoy learning science," "science is boring," "science is important to everyone's life," and "it is fun to build things." The outcomes of these questions were not included in GRG's final report, presumably because no significant changes in attitude were observed. Our hypothesis is that the greater variety of content in *Fetch*, while it tends to increase the viewership of the show, may decrease

Table 1
Student Agreement with Statements about Engineering (Goodman Research Group, 2007)

Positive Statements		Mean (Pre)	Mean (Post)
	Engineers solve problems that affect real people.	3.47	3.97**
	Engineers help make people's lives better.	3.65	3.95*
	Most people my age think engineering is cool.	2.77	2.94
	It would be fun to be an engineer.	3.57	3.61
	Engineering takes creativity.	4.08	4.19
	Engineers sometimes have to test their work and start again.	4.11	4.38*
	Engineers have fun doing their work.	3.93	3.96
Negative Statements	Engineering is boring.	2.44	2.10**
	Men are better than women at engineering.	1.80	1.62*
	Engineers sit at a desk all day.	1.47	1.52
	Only geniuses can succeed at engineering.	1.61	1.65
	Engineers usually work alone on projects.	2.04	2.02

*p <0.05, **p <0.01, 5 = strongly agree, 3 = neither agree nor disagree, 1 = strongly disagree the intensity of its impact on each viewer with respect to science and technology.

The assessments of *Design Squad* and *Fetch* conducted by GRG also sought to determine the degree of content knowledge retained by the viewers. The *Design Squad* assessments included free response items for each of the four episodes, asking viewers to list "two things you know now that you didn't know before you watched this episode." Unlike the pre- and post- surveys, these free response questions were administered immediately after viewing. The GRG team analyzed the viewer responses and coded them into different categories including "engineering content responses" and "descriptive responses." The GRG final summative report concluded that "across all four episodes, the majority of students demonstrated good recall and understanding of the series content" (Goodman Research Group, 2007). However, the details in the report suggest some caveats also need to be communicated. In the final report, GRG lists the percentage of viewers who wrote statements with "engineering content." Across all four episodes, the percentages ranged from 63% (for "Skunk'd") to 78% (for "The Need for Speed"), which appears to support the claim that a majority demonstrated "good recall understanding." But many of the statements made by viewers and which were coded as "engineering content responses" can also be interpreted as evidence of misconceptions of the series content. For example:

- A viewer, after watching "Need for Speed," wrote "I learned that if you push your weight to the front of your vehicle it will speed up." It is true that leaning forward was a key to going faster for one of the teams that had a front wheel drive arrangement and whose acceleration was traction-limited. However, the quote above reflects a poor understanding of the phenomenon presented in the episode. The viewer has generalized without noting the limitations of their conclusion.
- After watching "Rock On," a viewer stated "that when you hit a pipe the sound waves sort of bounce off each other." The show did discuss how sound results when a pipe is used in an instrument and an animation described sound waves being partially reflected at the open ends of the pipe. However, the statement of the viewer confused the material presented and is not consistent with a scientist's view of how sound waves interact.

The quotes above illustrate the types of misconceptions that can be carried away by viewers of a complex technical undertaking. Even though the program was developed with considerable care and presented clear explanations, the surveys show that viewer retention of those messages can often become muddled. These examples challenge the GRG report's contention that the majority of viewers "demonstrated good recall and understanding of the series content." They instead suggest that viewing of *Design Squad* seems to require substantial follow-up with knowledgeable educators, parents, and/or other children to further discuss what the show presented. Exposure to the engineering process and phenomena by viewing *Design Squad* is a good start, but the learning outcomes are mixed. This makes the outreach efforts associated with *Design Squad* all the more critical. These efforts are discussed in the next section.

Goodman Research Group (GRG) also conducted a summative assessment of learning outcomes for *Fetch*. Researchers administered pre- and post- surveys including 21 multiple-choice and fill-in-the-blank questions to a group of 168 fourth grade students who viewed five episodes of *Fetch* season #2. Several of these were related to engineering content including "Name the force that is pulling these go-carts down on the slope," "The force with which a ball strikes the pins in a bowling alley is determined by two factors: ___ and ___," and "which of the two airplanes will experience less drag?". A few more questions were related to design and experimentation processes such as "Jim thinks that the more air pressure in a basketball, the higher it will bounce .... How should he test this idea?"; "Imagine you must build a small toy sailboat. You have been provided with the materials ... What will you do next?". The average grades reported on this test rose from 13.3 to 15.4 out of 21 points and was found to be significant, with a p value less than 0.01. The improvement of about of 2 points out of 21 seems like a fairly large increment relative to other educational efforts. For example, ten years of data on Peer Instruction in Physics show average gains on concept inventories of less than 20% when pre-test scores are more than 50% (Crouch & Mazur, 2001) (and this increment is due to a semester-long course rather than a half-hour television program). One caveat though is that the 2 point gain observed for *Fetch* included questions with common misunderstandings actually reflected in the grading of the test. On the question "which of the two airplanes will experience less drag?" the aircraft presented were a WWI era Pfalz Flugzeugwerke bi-plane and a supersonic B-1 Lancer, and the answer coded as "correct" was the B-1 due to its lower drag coefficient, which the kids might be cued to notice because of the fairing shapes discussed in the episode "You Lucky Dog." But since the term "drag" used in the question more properly refers to drag *force* rather than drag *coefficient* and because the B-1 is larger and cruises at a higher speed under normal flight conditions and, therefore, actually experiences higher drag forces than any bi-plane, the coding of the response by GRG is questionable. One interpretation is that the ambiguities in the test itself account for more than the two points of average gains reported by GRG. Another interpretation is that the test demonstrates reasonably well what viewers actually did learn, because the particular ambiguities in the test (such as distinctions such as between drag coefficient and drag force) are not important for kids in the 6–10 age bracket.

An important goal of both *Design Squad* and *Fetch* is to give children insight into engineering and science *process* as well as content. Aspects of the summative assessments were directed at this objective. For *Design Squad*, GRG's pre- and post- survey items included a question: "Imagine you want to design and build your own bird house. Think about the steps you would need to take and check ALL of the statements that would be true." Similarly, for *Fetch*, pre- and post- survey items included several questions regarding the process of synthesis and investigation, such as "Imagine you must build a small toy sailboat and enter it into a race... With the help of a group of friends you build a small sail boat. What will you do next?" The GRG report for *Design Squad* reports that students correctly identified 7.8 steps in the design process before viewing and 8.3 steps after viewing, and that the improvement had an associated *p*-value less than 0.05. More specifically, *Design Squad* viewers more often selected steps related to generating multiple solutions rather than only a single solution, and more often recognized re-design as an essential part of the process. For comparison, the GRG report for *Fetch* also indicated improvement in process scores in general, and, in particular, more often recognized "brainstorming" and "redesign" as important. In addition, *Fetch* viewers showed an increase in appreciation for care in experimental design, including the need to identify "controlling variables."

Not only did *Design Squad* viewers more often identify ideation and redesign as important, but GRG also reported that the study participants were more likely to actually do these steps when posed with actual open ended challenges. In addition to the surveys, GRG administered small scale design challenges pre- and post- viewing to subjects in assigned pairs. One challenge was to build a bridge out of paper strong enough to support 100 pennies. The other challenge was to construct a device that could launch a paper ball twenty feet across the room. GRG researchers instructed the subjects "While you are thinking about what you will do, you can draw on this paper and work with the materials. We will ask you to talk about your ideas out loud, as we are interested in knowing what kids are thinking." GRG researchers observed and recorded the performance of the pairs. According to GRG's analysis of the discussions between the pairs, about 30% more pairs explicitly discussed "brainstorming" or developing many solutions.

Overall, the summative evaluation of *Design Squad* supports the contention that viewers are positively influenced by the program. Some changes in attitude toward engineering were shown to be statistically significant in *Design Squad.* In particular, attitudes improved relative to statements that relate to potential for a young person to pursue engineering professionally ("engineering is boring") or relate to the future diversity of the pipeline ("men are better than women at engineering"). The assessment results of knowledge content (for both *Design Squad* and *Fetch*) passed statistical tests for significance, were modest in effect size, but contain some significant uncertainties due to the design of the instruments. The assessment results (for both *Design Squad* and *Fetch*) also suggest that viewers tend to develop a greater appreciation for the need of multiple solutions and for testing and redesign as part of an overall process of dealing with technical challenges.

Evaluation of Audience Size and Composition

A key benefit of broadcasting is that even modest gains for each child can lead to significant overall impact due to the large number of children reached by popular media. This makes discussion of TV ratings data an important part of summative assessment of *Design Squad*. To provide some sense of the size and composition of the viewing audience, consider the data collected by Nielsen Media Research on PBS shows during April 2007 (Nielsen Media Research, 2007). Figure 9 indicates the ratings for various PBS television programs. The figure includes a wide range of comparators in the reality-based format (*Antiques Roadshow, This Old House,* and *Fetch*), educational programs (*Nova, Sesame Street, Cyberchase, Between the Lions,* and *Fetch*), shows with engineering content (*This Old House, Motorweek* and *Fetch*), and children's programs (*Bob the Builder, Sesame Street, Cyberchase, Maya and Miguel, Between the Lions,* and *Fetch*).

Design Squad earned a 0.2 rating for the period which is the lowest of all the 57 PBS shows in the Nielsen study for April. The rating of *Design Squad* in May was much better at 0.4, but *Fetch* was not evaluated that month. The highest rated PBS show during April 2007 was *Antiques Roadshow* at 4.6 (roughly 25 times as many households as *Design Squad*). The ratings for *Antiques Roadshow* are about one quarter of the highest rated network programs for general audiences, but are comparable to the highest rated children's shows on network and cable. *The Suite Life of Zack and Cody* earned ratings on the order of 5.0 at its peak and shows like *Hannah Montana* have had similar ratings. However, children's shows on PBS rarely have such a large audience (one exception is that *Arthur* briefly had ratings above 4.0 on PBS around the time of its launch). The highest rated children's show on PBS during April 2007 was *Bob the Builder* at a 1.5 rating. *Fetch* earned a 0.7 rating indicating that roughly three times as many households tuned in to each showing of *Fetch* as compared to *Design Squad*.

The difference in audience size for *Fetch* and *Design Squad* is of particular interest here because of its possible relationship to differences in content and style of the shows. As described above, *Fetch* has a lighter style of

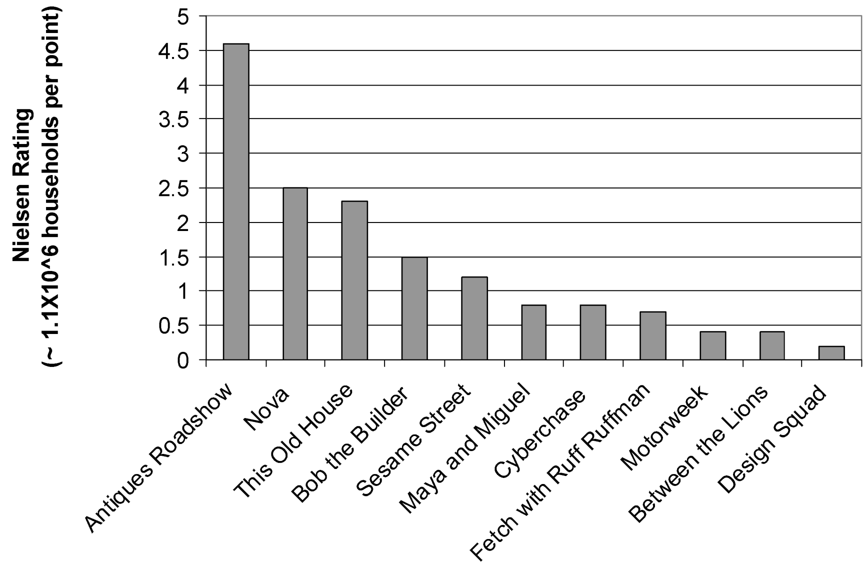

Figure 9. Nielsen ratings for a variety of PBS programs (both adult and children's) in April 2007 (Nielsen Media Research, 2007).

delivery than *Design Squad* and a greater variety of material, including cultural elements as well as science and engineering. Content and style are probably the largest factors determining the ratings, but much of the difference between *Design Squad* and *Fetch* is due to other factors. *Design Squad* had only 60% coverage in April 2007 (the fraction of PBS stations that carry the show) as compared with 90% coverage for *Fetch* (Nielsen Media Research, 2007). A mitigating factor is that coverage of *Design Squad* in the 25 biggest markets was about 80%. Another issue to consider is the difference in the times the shows are run. For example, *Fetch* generally runs Monday through Friday shortly after school lets out (it airs between 3:30 pm and 5:30 pm depending on the station). By comparison, *Design Squad* usually runs during the weekends. Most of the slots are fairly good for children's viewing (e.g. 9:30 am on Saturday in Chicago), but some are quite unfavorable (e.g. 6 am on Saturday in Washington DC). Also significant is that *Fetch* generally runs more times per week (five times in most markets) as compared to *Design Squad* (usually once per week on the stations that carry it). Considering the difference in ratings and the factor-of-five difference in frequency of airing each week, the cumulative weekly viewership of *Fetch* is many times that of *Design Squad*. Despite low ratings relative to other TV programs, the audience size for *Design Squad* is still fairly large—280,000 viewers per week in April and 570,000 viewers per week in May tuned in for at least 5 minutes (Nielsen Media Research, 2007). In addition, there are probably substantial additional viewers on-line not recorded by Nielsen's methods. WGBH estimates the *Design Squad* website gets about 55,000 visitors in an average month.

Also of interest is the age distribution of viewers of *Design Squad* and *Fetch*. Figure 10 graphically depicts the cumulative weekly viewership trends based on data from for April 2007 for *Fetch* and averaging April 2007 and May 2007 for *Design Squad*. Note that these cumulative values in Figure 10 account for the number of times shows are broadcast and the values in Figure 9 do not. *Design Squad* has a good proportion of viewers in the 12 to 17 year bracket, which is a good match to the format and content of the program. The viewership among teens is about as good as among other age brackets. This relatively high appeal among teens is unusual among PBS shows, especially

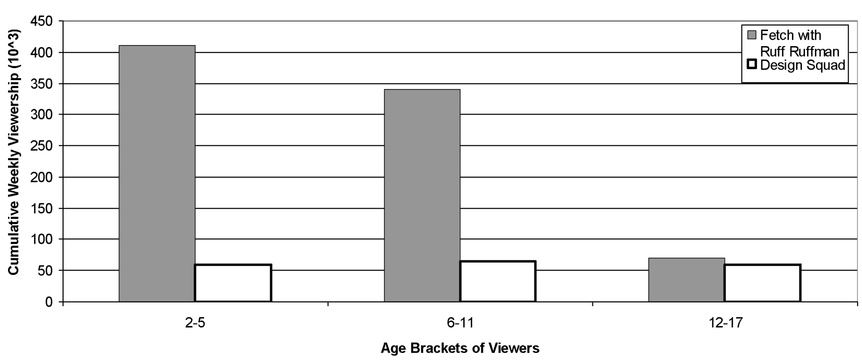

Figure 10. Age distribution of cumulative viewers per week for *Design Squad* and *Fetch with Ruff Ruffman* for April 2007.

children's shows which tend to have more viewers in the younger categories. In May 2007, about one in six viewers of *Design Squad* were teens, which was the highest proportion of all PBS shows that month. Among PBS programs in May 2007, only *Antiques Roadshow* had more teen viewers in absolute terms. The high appeal of *Design Squad* among teens is probably substantially due to the age of contestants on the show and the more advanced content, as described above. However, these trends may also be partly due to its airing times on weekends, when the viewing audience on PBS generally shifts to older age ranges. The weekend line ups on PBS are accordingly composed of shows like *This Old House,* which, although they are primarily adult programs, also have a good appeal in *Design Squad*'s target age group and also present some technical content. Although it is not shown in Figure 10, some data is available on the ethnic, racial, and gender make-up of the PBS viewing audiences. *Design Squad*'s viewing audience includes a large proportion of Hispanic households (as high as 27% in some months). This proportion is higher than that of some PBS shows with explicit Spanish language content, such as *Maya and Miguel* and *Dora the Explorer*. *Design Squad*'s viewing audience has about as many girls as boys which is good in comparison to other weekend "how to" shows, such as *This Old House,* which has about twice as many boy viewers as girls.

Also shown in Figure 10 for comparison is the age distribution for *Fetch*. This program has a strong appeal in the 6 to 11 age range, which is its primary target range, and has proportionally less of its audience in the 12 to 17 year old bracket, which is the main audience for *Design Squad* (although in absolute terms, *Fetch* has more viewers per week than *Design Squad* in this category too). It is interesting that *Fetch* has more viewers in the range 2 to 5 years old than any other age category, even though it is not primarily designed for these very young viewers. The age distribution of *Fetch* viewers is fairly typical of other children's shows on PBS, such as *Cyberchase* and *Bob the Builder*. This reinforces the suggestion that age distribution of PBS viewers is driven by the airing times even more than the program content.

Outreach Efforts

As described above, the motivation for *Design Squad* is not to lead students to watch more television, but to promote interest in real-life design project activities. Fortunately, there is some evidence that viewing *Design Squad* accomplishes this objective. In the summative assessment study, viewers were asked before and after viewing to indicate their degree of interest in various types of after-school programs. The survey presented a five-point scale ranging from 1 (not at all interested) to 5 (extremely interested). Interest in programs "where I could work on designing and building" and "science programs" did not register a significant change. However, the survey did indicate a statistically significant (α=0.05) change in the degree of interest in "engineering programs," with an effect size of 0.25 points on a 5 point scale.

To carry through with active engagement with viewers, WGBH has developed an event guide and associated training. The purpose of the guide is to help engineers and other informal educators to lead design project activities after school. The guide provides general advice about forming clubs related to the *Design Squad* series and specific instructions for three different design/build projects. The projects are of a very simple kind, involving materials typically found in homes or at hardware stores. For example, one of the projects is a rubber-band-powered car constructed with a cardboard body, CDs as wheels, and a thin wooden dowel as an axle (see Figures 5 and 11). The *Design Squad* event guide is freely available on the website (WGBH Educational Foundation, 2007a). Through the website and through live events, the guide has been distributed to about 35,000 engineers and informal educators. WGBH estimates that about 30,000 children have completed design/build projects at public events. This is good news in the sense that the absolute number of students doing the projects is large. On the other hand, probably fewer than 1 in 10 viewers have followed up with a real-world design activity.

Conclusions

The story of *Design Squad*'s development is potentially instructive for other programs with goals to bring engineering content to a young audience in an informal setting. The team at WGBH and MIT pursued a reality-based format including difficult technical content. As the *Boston Globe* noted in its review (Weiss, 2007), this content would require more focused attention and motivation of the viewers than TV usually demands. This may have contributed to the relatively small audience for *Design Squad*. By comparison, *Fetch with Ruff Ruffman* presented simpler engineering and science ideas and incorporated more balance, with arts, humanities, and social sciences. The audience for *Fetch* has been substantially larger across the target it shares with *Design Squad,* and even in *Design Squad*'s target, that is above the intended range for *Fetch*.

One key lesson may be that content creation alone will not enable popular media to impact the pipeline for engineering education to the degree that is needed. To have a significant impact on the pipeline issue, engineering content has to draw a large enough audience. If the engineering community wants to reach young people in their living rooms, it may have to do more to meet the viewers' expectations—to accommodate what people usually seek when they turn on the television. Alternately, the engineering community might create

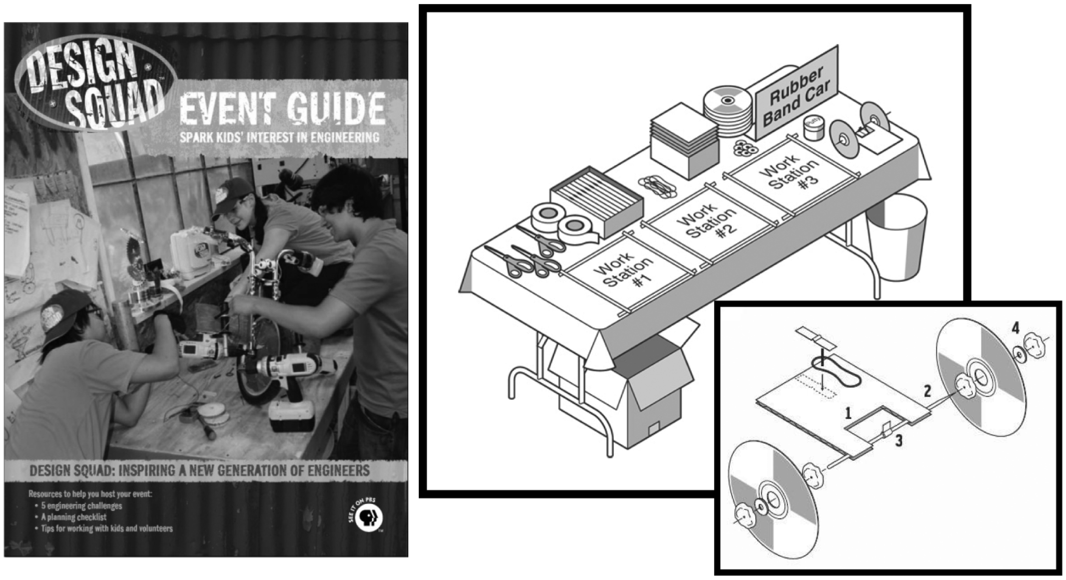

Figure 11. The *Design Squad* event guide, "Challenge Table", and one of three design projects described therein.

programming similarly focussed and demanding, but find alternative means to draw the audience. For example, they can seek connections between formal and informal education. For example, *Design Squad* and similar content can be used by middle school educators to support in-class instruction or homework.

Another key lesson may be that such tight focus on engineering is not quite right for the medium of television. Those young people that are strongly enough inclined toward *Design Squad* technical content may want to do much more than just watch the designing and building. There may need to be a rather short bridge from viewing a program like *Design Squad* to engaging personally in a design process. If that turns out to be true, how could the engineering community create such a bridge, and exactly where will it lead? Programs like *FIRST* seem to work very well to engage technically-inclined High School students. *FIRST* Lego league is a step toward linking such programs to middle-school-aged children. Is there a role for programming like *Design Squad* as a recruitment tool into the realm of hands-on engagement?

It is worth considering what the story of *Design Squad* says about interactions between media organizations and institutions of higher education. WGBH and MIT were able to work together to create the first two seasons, but the cultural divide was strongly evident throughout the project. The divides were most strongly felt in regard to how information could be shared and discussed outside of the development team. Faculty take for granted a substantial degree of openness about work in which they engage (with some exceptions for private consulting under non-disclosure agreements). Media professionals seek out information for use in development of programs, but generally are not in the habit of distributing information any further than needed after that. As Rockman (2007) observed, research on broadcast media appear as "fugitive literature" inaccessible to most researchers. This private treatment of data includes market research and even educational outcome studies funded by the National Science Foundation. Due to such cultural differences (and perhaps other factors as well), the third and fourth seasons of *Design Squad* have been produced without any MIT involvement. A study of the multi-year trends in the content, audience, and outcomes would be possible to undertake and might help to reveal interesting patterns in the content and style of the program as a function of the organizations and individuals that were involved over time.

As possibilities for future research, a variety of possibilities exist. A longer-term study of impacts of *Design Squad* might be undertaken. It is known that informal educational programs often work best in an ecosystem of related opportunities (National Research Council, 2005). For example, a magazine article can raise interest leading readers to visit a museum. A museum exhibit might subsequently lead to participation in a school activity. It would be interesting to know if *Design Squad* has catalyzed such chain reactions with significant frequency.

Another interesting long-term study, from the perspective of design education, might be a longitudinal assessment of the cast members from *Design Squad*. From personal experience, the one fact known to the authors is that one out of eight cast members from season #1 is enrolled in an engineering degree program. We would like to know much more. After such an intense exposure to engineering design, these cast members should have had an unusual insight into engineering. Did they find it appealing? Was it overly intense leading to burn-out? Perhaps the participation in *Design Squad* was more strongly an experience in broadcasting than in engineering *per se*. What other factors affected the career choices of the cast?

As described on its website, the *Journal of Pre-College Engineering Education Research* is "dedicated to addressing the downward trends in engineering interest, preparedness, and representation; … and ultimately to creating a society of engineering–literate citizens." This paper has argued that popular media must be part of that mission. For good or for ill, young people are strongly engaged with visual media such as television and the internet. It is likely that these media have contributed to the interrelated societal problems of inadequate pipelines to the engineering profession and poor public perceptions of engineering. Bringing thoughtful and well-designed engineering content into these media is a start, and *Design Squad* has certainly contributed to that.

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