Chapter 11

How the Science Entertainment Television Show *MythBusters* Teaches the Scientific Method

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Additional information is available at the end of the chapter

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Abstract

All too often, high school—and even university—students graduate with only a partial or oversimplified understanding of what the scientific method is and how to employ it. The long-running Discovery Channel television show *MythBusters* has attracted the attention of political leaders and prominent universities for having the potential to address this problem and help young people learn to think critically. *MythBusters* communicates many aspects of the scientific method not usually covered in the classroom: the use of experimental controls, the use of logical reasoning, the importance of objectivity, the operational definitions, the small-scale testing, the interpretation of results, and the importance of repeatability of results. In this content analysis, episodes from the show's 10-year history were methodically examined for aspects of the scientific method.

Keywords: science education, television, science entertainment, popular science, *MythBusters* scientific method, repeatability, objectivity, experimental design

1. Introduction

The importance of understanding and internalizing the scientific method can hardly be exaggerated: "The future of man depends upon his skill in solving problems … Recent successes in problem solving have brought about enormous changes in agriculture, industry, transport, medicine, and communications, which have considerably changed the pattern of human life and death" [1]. Unfortunately, it is all too common for high school—and even university—students to graduate with only a partial or oversimplified understanding of what the scientific method is and how to employ it.

Help in remedying this situation may come from an unlikely source: television. While most educational pundits bemoan the hours children spend transfixed by television, a few select

programs are teaching the scientific method and how it is applied. One television show that is conspicuously good at teaching the scientific method in an easy-to-understand, pedantic-free, entertaining manner is the Discovery Channel's *MythBusters*, which began airing in 2003. Indeed, *MythBusters* has attracted the attention of political leaders and prominent universities for having the potential to help young people learn to think critically.

For those unfamiliar with the show, its premise involves the hosts (Adam Savage, Jamie Hyneman, and build team members Tory Belleci, Kari Byron, and Grant Imahara) testing the validity of various urban legends, folk tales, common idioms, historical accounts, and internet viral videos using the scientific method: "Mr. Hyneman and Mr. Savage employ thinking and processes that are grounded in scientific method … They come up with a hypothesis and test it methodically" [2]. A myth can be deemed "confirmed," "busted," or "plausible," if possible though highly improbable.

While the focus of the show is on entertainment, the hosts rigorously adhere to the scientific method: "The show's genius is that beneath the kinetics and risky stunts – spectacular car crashes, explosions and other dangerous merriment – is a cleverly veiled science show that instructs as it entertains, which any teacher will tell you, is a real feat" [3].

MythBusters provides such a wealth of insight into the process of scientific discovery, in fact, that recently Stanford University created an entire course based on the show [4]. In the freshman course, "The Science of *MythBusters*," students learn the scientific method and how to think critically using excerpts from the show [5].

Indeed, *MythBusters* is so effective at communicating the scientific method that President Barack Obama has appeared on the show commending the hosts and stressing the importance of the show's contributions to the society: "[N]othing is more important to our country's future than getting young people engaged in math and science. A lot of the challenges that we face as a country are going to depend on how engaged young people are in science and so I'm just thrilled that you guys do such a great job making it fun ["President's Challenge" [Original Air Date (OAD): 12/8/2010].

The scientific method is far richer and more nuanced than the abridged "five-step" system commonly disseminated in classrooms (define the problem, make observations, formulate a hypothesis, test the hypothesis by experiment, and draw a conclusion—confirm, abandon, or modify the initial hypothesis) [6]. The scientific method is "the method by which … knowledge is … won … an intellectual tool … a probe for exploring the unknown" [1]. *MythBusters* teaches many aspects of the scientific method not usually covered in the classroom: the use of experimental controls, the use of logical reasoning, the importance of objectivity, the operational definitions, the small-scale testing, the interpretation of results, and the importance of the repeatability of results.

2. Methodology

Complete seasons of *MythBusters* were downloaded from Apple's iTunes Store, and the episodes were systematically analyzed in chronological order for aspects of the scientific method. The most common aspects quickly became evident, and examples illustrating those were sought in the content analysis of the remaining episodes. Narration and dialog were transcribed, and in

cases of ambiguity, subtitles were consulted. The examples contained in this treatment should not be taken as exhaustive nor necessarily the most compelling, i.e., cherry-picked. For the sake of brevity, many equally illustrative examples could not be included. The analysis conducted was qualitative (descriptive) in nature [7–9]. Further work would be needed to treat the show in a quantitative manner (such as determining the frequency of certain aspects of the scientific method per episode and season) and was beyond the intended scope of this text.

Additionally, we designed and implemented a classroom activity to introduce the scientific method with a particular emphasis on experimental controls that utilized myths from the show. We did this with two sections (10 and 12 students) of the twelfth grade Regents Physics (designed to prepare students for statewide standardized examinations) at Onondaga High School near Syracuse, New York. The time commitment was approximately 90 min (1.5 days on an A/B schedule of alternating short and long classes). Complete activity details and materials are available online [10]. Because the format of each episode is to feature several different myths and to jump back and forth between them, we found that it is highly useful to make a note beforehand of the times of the specific segments we wanted to show, allowing us to present a myth in an uninterrupted manner, improving coherence and saving time.

3. Proposing a hypothesis

Before conducting an experiment, the *MythBusters* offer their opinion on what they think will happen; that is, they formulate a hypothesis: "Hypotheses can be considered as possible answers to problems … hypotheses do not as yet constitute real knowledge … [they] are … 'candidates for truth'" [11].

In the "Anti-gravity" myth ["X-mas Lights and Anti-Gravity Device"—OAD: 12/19/2007], Tory, Kari, and Grant test internet-bought gadgets that purportedly employ antigravity in their operation (**Table 1** Entry 1). **Table 1** provides a brief summary of all myths discussed

Myth	Episode Title	OAD	Description	Result
1. Anti-Gravity	X-mass Lights and Anti-Gravity Device	12/19/2007	Various internet-bought gadgets employ anti-gravity in their operation	Busted (for now)
2 Depth Charge Disaster	Paper Armor	6/29/2011	A person can increase the chances of surviving an underwater explosion by floating on his back at the surface rather than diving or treading water	Confirmed
3. Brain Drain	Tablecloth Chaos	10/27/2010	People only use 10% of their total brain capacity	Busted
4. Diet Coke and Mentos	Diet Coke and Mentos	8/9/2006	Why does dropping a Mentos point into a bottle of Diet Coke create a geever effect	N/A
5. Cockroach Survival	Airplane on a Conveyor Belt	1/31/2008	Cockroaches on the only organisms able to survive the radiation exposure from the fallout of a nuclear war	Busted

Myth	Episode Title	OAD	Description	Result
6. Red Flag to a Bull	Red Flag to a Bull	8/22/2007	The color red provokes bulls to change	Busted
7. Eye Patch	Pirate Special	1/17/2007	Pirates wore eye patches to preserve night vision	Plausible
8. Talking to Plants	Exploding House	11/14/2004	Talking to Plants or playing music can help them grew	Plausible
9. Animal Magnetism	Shark Week Special	7/27/2008	Magnets can repel sharks	Busted
10. Play Dead	Shark Week Special	7/27/2008	In shark-infested waters, it is better to 'play dead' than to thrash about	Confirmed
11. No pain, No Gain	No pain, No Gain	4/28/2010	A person's threshold to pain can be increased by cursing	Confirmed
12. Request Fest	Mini Myth Madness	11/10/2010	Underinflated tires can significantly reduce fuel economy	Confirmed
13, Eye Block	Viewer Special2	2/13/2008	Base players wear black makeup under their eyes to reduce glare from the sun	Plausible
14. Vodka Myths: Top Shelf Filtration	Bullets Fired Up	4/19/2006	One can turn cheap low-quality vodka into high-quality vodka by filtering it repeatedly through a chargoal filter	Busted
15. Battle of the Sexes	Battle of the Sexes	4/22/2012	Tested whether men or women are better at various tasks including reading facial expressions driving and cooling	Mixed
16. The Smell of Fear	Fright Night	10/28/2012	Humens give off a detectable scent when scared	Plausible
17. What is Bullet Proof?	Coffin Punch	11/5/2008	A sufficiently cloese person will have his internal organs protected from a bullet by the overlying layer of fat	Busted
18. Beer Goggles	Alcohol Myths	10/22/2008	Consumption of alcohol can make one perceive others as more physically attractive than while sober	Plausible
19. Taking Candy From a Baby	Mini Myth Madness	11/10/2010	It is easy to take condy from a baby	Busted
20. Square Wheels	Square Wheels	4/8/2012	Square wheels can provide a smooth ride if the vehicle is driven fast enough	Plausible
21. Driving Dangerously	Driving in Heels	4/29/2012	Certain types of shoe can seriously compromise a person's ability to drive car	Busted
22. Tryptophan Turkey	Surreal Gourmet Hour Food Fables	11/18/2012	Eating turkey makes people drowsy due to its tryptophan content	Busted
23. Water Heater Rocket	Exploding Water Heater	11/7/2007	A malfunctioning pressure release can cause a water heater to explode through the multiple floors of a house like missile	Confirmed

Myth	Episode Title	OAD	Description	Result
24. Bourne Magazine	Bule Ice	4/13/2011	A room filted with flammable gas can be made to explode by ignitting a magazine with a toaster	Busted
25. What is Bomp Proof?	Running on Water	4/20/2011	Various objects including tables, dumpsters, cars, and cinderblock walls will prodect a person from an explosion	Plausible
26. Let There be Light	Let There be Light	6/22/2011	A system of mirros can redirect sunlight to illuminate a tomb suffieciently to navigate safely through	Plausible
27. Down with the Titanic	Goldfish Memory	1/25/2004	A sinking ship generates a vortex powerful enough to suck people in the sorrounding water down with it	Busted
28. Bubble Trouble	Bubble Trouble	4/27/2011	It is impossible to swim in bubbly water	Plausible
29. Wrecking ball Baloney	Newton's Crane Cradle	10/27/2010	It is possible to construct a working Newton's cradle using wrecking balls	Busted
30. Tablecloth Chaos	Tablecloth Chaos	10/27/2010	It's possible to use a motorcycle to pull a tablecloth free of a banquet table without distubing a single place setting	Busted
31. Surfing with Dynamite	Lead Balban	1/23/2008	A person can surf on a wave generated by dropping a few pound of explosives in a body of water	Busted
32. Drain Disaster	Drain Disaster	11/2/2011	A methene explosion in a sewer can launch a manhole cover into the air	Confirmed
33. Vatkyrie Boom	Vatkyrie Boom	12/22/2010	An attempted assassination of Hitler failed because the explosion occurred in an aboveground room with windows and not in an enclosed bunker	Busted
34. Trench Torpedo	Trench Torpedo	10/14/2012	WWI trenches were built with right angle corners to limit the prooagation of shock waves	Plausible
35. The Haunted	Fright Night	10/28/2012	A 19 Hz inaudible tone may be responsible for peoples' perceptions of certain buildings as being haunted	Busted
36. Primary Perception	Deadly Straw	9/6/2006	Plants are conscious and capable of exhibiting emotions, such as fear and anger, detectable by polygraph	Busted

Note: Myths appear in the order in which they are discussed.

Table 1. Synopsis of myths discussed herein to be consulted by the reader for clarification.

herein for convenient reference. Grant explicitly states his hypothesis for the audience: "My suspicion about what's going on here is that the large DC voltage is ionizing the air around the lifter and it's creating a flow of ions, which is bringing air along with it, creating thrust. Now, what we can do to prove this, or disprove it, is to remove all of the air. If that's the case, then there should be no thrust." Inherent in all good hypotheses is testability. A hypothesis must be capable of being either supported or refuted, as Jamie explains, "That's science: you come up with a theory, you test it, either it works or it doesn't" ["Walk a Straight Line"—OAD: 10/12/2011].

No matter how eloquently formulated, a hypothesis must be empirically tested before gaining credibility. As the narrator notes, "[T]his is *MythBusters* and it's not a fact until you test it" ["Blue Ice"—OAD: 4/13/2011]. In the "Depth Charge Disaster" myth ["Paper Armor"—OAD: 6/29/2011], the *MythBusters* test whether it is safer to lie supine on the surface rather than diving or treading water in the event of an underwater explosion (**Table 1** Entry 2). Before getting underway, both Adam and Jamie voice their skepticism about the myth, but as the narrator cautions the audience, "So both *MythBusters* are skeptical, but science is an evidence-based discipline."

In addition, no matter how well accepted or long standing, a hypothesis is still subject to reevaluation and scrutiny, as demonstrated in this exchange among the build team members in the "Brain Drain" myth (**Table 1** Entry 3) ["Table Cloth Chaos"—OAD: 10/27/2010]:

> *Kari: "We are testing a myth that is so prevalent that it's just taken for granted that it's fact: humans only use 10% of their brain."*
>
> *Tory: "You hear that everywhere. It's like ingrained in our society."*
>
> *Grant: "Definitely. But that doesn't necessarily make it true."*

Occasionally, competing hypotheses to explain a phenomenon exist: "Rival hypotheses constitute alternative, incompatible or disjunct answers to some problem" [11]. This is vividly demonstrated in the "Diet Coke and Mentos" myth ["Diet Coke and Mentos"—OAD: 8/9/2006] when Adam and Jamie test different hypotheses for the vigorous reaction that ensues when Mentos mints are added to a bottle of Diet Coke (**Table 1** Entry 4). Various tendered explanations implicated the ingredients of the soda and the pitted surface of the mints. If dissolved CO_2 were the only factor, then a mint added to soda water should bring about the same reaction as a mint added to Diet Coke: "If CO_2 is the only factor, these two things should spurt the same height," explains Adam. When the reaction with the soda water proves anemic by comparison, the *MythBusters* conclude that some other component of the Diet Coke is responsible for the energetic nature of the reaction. They go on to test each possible culprit—aspartame, citric acid, phosphoric acid, caffeine, and potassium benzoate—by mixing with soda water and noting the intensity of the reaction with a Mentos mint. On the contribution of the mint to the violent reaction, Adam states "The most common theory about what's going on in this reaction between the candy and the soda is what's called nucleation. Basically, the idea is that the surface of the candy is covered with microscopic pits and more surface area than you can actually see and each little pit, each little corner, provides what's called a nucleation site or a place where a carbon dioxide bubble can form and escape." To test this hypothesis, the *MythBusters* compare the reaction intensity of Diet Coke with two

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kinds of Mentos mints—one pitted and one covered in glaze—both made by the same company: "These two candies are made by the same manufacturer … using the same process but the colored version of this actually has a glazing over it – it's a wax coating or a sealer – that inhibits the nucleation process that the other one achieves quite readily," explains Jamie. If nucleation sites are what permit the CO_2 to rapidly bubble out of solution, then the reaction of the Diet Coke with the smooth mints should be much less vigorous than with the pitted mints. The *MythBusters* enumerate various competing hypotheses to account for an observed phenomenon and design experiments to systematically test each one.

4. Designing and carrying out an experiment

The *MythBusters* are thorough in their design of experiments, carefully noting to use controls and employing single-blind and double-blind techniques to avoid introducing bias and tainting the obtained results.

The use of controls in experiments is of paramount importance: anticipating and accounting for confounding variables are essential in the design of a good experiment. In "Cockroach Survival" ["Airplane on a Conveyor Belt"—OAD: 1/31/2008], Tory, Kari, and Grant test the commonly held belief that the only life forms to survive the radioactive fallout from a nuclear war would be cockroaches (**Table 1** Entry 5). They expose cockroaches and other insects to varying levels of radiation (1 kilorad, 10 kilorad, and 100 kilorad) and maintain a fourth set as a control with no exposure to radiation. This establishes a baseline for comparison. While none of the insects in the control receive any radiation exposure, they could die from other factors: "Scientific studies must adequately control for alternative explanations of observed data" [12].

In "Red Flag to a Bull" ["Red Flag to a Bull"—OAD: 8/22/2007], the build team tests the idea that bulls are angered by the sight of a red flag (**Table 1** Entry 6). In the design of the experiment, the build team tests not just the effect of different colors (red, blue, white flags) but the presence of motion and the presence of a person. They come up with an experimental checklist to determine whether it is color or some other variable that provokes a bull to charge:

1. Single static flag—red, white, and blue
2. Comparative static flag—all three flags
3. Moving flag compared to color
4. Human form with moving flags

In part 1, only one flag is present in the arena at any one time as it might not be color that angers a bull but the fact that it is the only salient object in an otherwise featureless pen. The result is that the bull charges all three flags. In part 2, all three flags—red, white, and blue—are hung in the arena to see if the bull prefers a certain color but charges all three. In part 3, the experiment tests the idea that it is a moving flag and not a red flag that infuriates a bull. This part of the experiment consists of a red stationary flag and a blue flag on a pulley being pulled

back and forth with the result that the bull only charges the moving blue flag, not the stationary red flag. Therefore, it is movement that triggers an aggressive charge response and not the color red. In part 4, foam dummies in human form with waving and flapping flags—red, white, and blue—add a human element to the experiment. The last flag left standing is the red one with the blue and white flags taken down first. In this way, the *MythBusters* account for factors other than color: "Any extraneous variable that could provide an alternative explanation for the observed statistical relationships should be accounted for to show that none of these alternative explanations are the real explanation for the findings" [12].

The use of controls also factors prominently in the "Eye Patch" myth (**Table 1** Entry 7) ["Pirate Special"—OAD: 1/17/2007]. The build team tests the myth that pirates did not wear eye patches to cover an eye gouged out in battle but rather to keep one eye constantly night vision ready. In this way, one eye would always be dark-adapted so that if the pirate had to go below deck or enter a battle at night, he could see without difficulty. The build team designs an obstacle course to test the myth. As the designers, they are not permitted to navigate the course themselves: "If we're building this obstacle course, we're not going to be able to test it," notes Tory. Instead, they have Adam and Jamie each navigate the obstacle course, first using the eye that was exposed to bright light (with the dark-adapted eye kept under the patch) and then using the dark-adapted eye. To prevent Adam and Jamie from clocking a faster time owing to familiarity with the course, the obstacle course is rearranged before the second run. As an additional control, Adam and Jamie are made to run the course a third time to prove that the faster times are due to enhanced night vision provided by the dark-adapted eye and not due to familiarity with the course by leaving the course unaltered from the second trial and having them run it without dark-adapted vision. As Kari explains, "We've left the course exactly the same as when they went through it with the adjusted night vision eye. This way we can totally, empirically prove that if they can get through this course and it takes them twice the time or any more time than it took them with their adjusted eye, we've … proved this myth … And as one last variable of final control, we sent them through that obstacle course one last time with their daylight vision, taking out the them knowing the course, and they still messed it up just as bad as the first time they went through."

While some of the myths tested on the show strain plausibility, a robust scientific methodology is still employed. This dichotomy between silly myth and sound science is no more evident than in the "Talking to Plants" myth (**Table 1** Entry 8) ["Exploding House"—OAD: 11/16/2004]. To test whether sound can influence the growth of plants, the build team set up several green houses with pea plants inside. Some houses are exposed to recorded dialog, some to music, while silence is maintained in others as a control. As the narrator explains, the only variable is to be the sound: "As far as possible, conditions will be identical for all the plants except, of course, the sound." When a timer that controls watering fails, all plants experience a lack of water and wither. However, as the narrator explains, "The only upside: every green house was affected in exactly the same way. So, although the plants aren't a picture of health, the experiment is still valid."

The *MythBusters* also incorporate the use of controls in their experiments for testing of "Animal Magnetism" (**Table 1** Entry 9) ["Shark Week Special"—OAD: 7/27/2008]. The essence of this myth is that sharks are repelled by magnetic fields, which interfere with their sensory apparatus. An initial test employs a control: "I'm putting a plastic card over the shark's eye so that we can be sure that he's reacting to the magnetism itself and not to

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the sight of the magnet being brought close to him," explains Adam. In a second test, the *MythBusters* place a line of magnets across a tank to see if a shark will cross the magnetic boundary. As a control, they put down a line of similar looking lead weights to make sure the shark is not responding to the visual cue. As Adam explains, "You're going to say, 'But the shark is just disturbed by seeing a big line of stuff in their tank.' Well, we've already thought of that, that's why we're going to start with a control. We're going to lay a line of these innocuous lead weights across the tank and hopefully we'll see the shark not care about these at all from a visual standpoint … For the control, we expect to see the shark swim up and down this track with no inhibitions. Then, we're going to place a line of magnets somewhere along that track and see if the shark either resists crossing that line of magnets or doesn't care that they're there at all." The *MythBusters* anticipate and account for possible alternative explanations of an observed phenomenon, just as students should be encouraged to use their imaginations to think of possible alternative explanations for the observed relationships between variables [12].

In the "Play Dead" myth ["Shark Week Special"—OAD: 7/27/2008], the build team tests whether sharks are attracted to erratic, jerky movements (**Table 1** Entry 10). In the experiment, Tory thrashes about in shark-infested waters, while Grant floats calmly nearby in the same waters. As a control, they reverse roles: Grant then thrashes about, while Tory plays dead. This is done to ensure that the sharks are attracted to movement and not something unique to the individual, as Kari explains, "They might have just been attracted to Tory; he might have been a bigger target."

In testing whether swearing helps increase one's threshold to pain ["No Pain, No Gain"—OAD: 4/28/2010], the *MythBusters* recognize that they must isolate the act of swearing from the act of speaking (**Table 1** Entry 11). To do so, Jamie and Adam have participants vocalize similar sounding non-swear words as a control while having their hands submerged in ice water.

When testing whether underinflated tires reduce fuel economy ["Mini Myth Madness"—OAD: 11/10/2010], the *MythBusters* stress the importance of accounting for other factors that may affect fuel economy (**Table 1** Entry 12). As Grant notes, "We have to have a very specific route. We'll have to drive the same route every time at the same speed in the exact same way … the weight of the car cannot change between tests. That's the only way we'll be able to compare our results."

In addition to accounting for other variables through the use of controls, the *MythBusters* also frequently employ single-blind and double-blind experimental procedures to avoid introducing bias into the obtained results.

In the "Eye Black" myth ["Viewer Special 2"—OAD: 2/13/2008], the *MythBusters* test whether applying black makeup to the skin beneath the eyes reduces glare in bright light (**Table 1** Entry 13). To ensure the validity of the results, the test subject is not told if he is wearing the black makeup. As a control, regular flesh-tone makeup is applied in one trial and the eye black in another trial. The test subject is not allowed to know if he has received the control or the variable under question as knowledge could influence the self-reported results.

In the "Top Shelf Filtration" myth ["Bullets Fired Up"—OAD: 4/19/2006], the *MythBusters* test whether it is possible to turn cheap, low-quality vodka into premium, high-quality vodka by filtering it repeatedly through a charcoal filter (**Table 1** Entry 14). Three participants are each given eight samples of vodka: one from each of six filtration stages, one shot of high-quality vodka, and one shot of unfiltered cheap vodka. They are asked to rank them in order of perceived quality. The experiment is conducted in a double-blind setup; participants and the administrator of the test are kept ignorant of the identity of each sample. As Grant elaborates, "These samples have been prepared and randomized. Even I won't know which is which until the very end."

In the "Battle of the Sexes" ["Battle of the Sexes"—OAD: 4/22/2012], the *MythBusters* test whether men or women are better at various activities, such as driving and cooking (**Table 1** Entry 15). In each of these experiments, they ensure that those conducting the assessments are kept unaware of the gender of the participants to prevent potential bias. As Adam explains, "[T]o eliminate bias we should make sure that the driving instructor does not know the gender of the person he's testing at any given moment." Later, Jamie reminds the audience of the need to avoid introducing potential bias: "The grilling will be assessed by a panel of judges. [T]his is a blind test, which means that the judges will not know the gender of the people that are preparing the food that they're tasting."

In the "The Smell of Fear" myth ["Fright Night"—OAD: 10/28/2012], the *MythBusters* test whether fear-induced perspiration noticeably differs from exertion-induced perspiration (**Table 1** Entry 16). To test this myth, they collect samples of sweat exuded during exercise and exuded while experiencing fear and see if volunteers can distinguish between them. To prevent the introduction of bias, a double-blind format is employed, as Grant explains, "So for our smell of fear experiment, it will be double-blind, meaning neither the volunteers nor Tory, who is administering the test, will know what sample is what."

In their design of experiments, the *MythBusters* are careful to incorporate controls and to employ a single-blind or double-blind format to prevent introducing bias.

5. Formal logic

MythBusters demonstrates the importance of logical reasoning in science. This syllogistic logic is best explained by way of a simple example:

> *"B = A.*
>
> *B = C.*
>
> *Hence A = C" [13].*

The use of formal logic is demonstrated in the "What is Bullet Proof?" myth (**Table 1** Entry 17) ["Coffin Punch"—OAD: 11/5/2008]. The myth centers on the idea that a sufficiently obese person will have his internal organs protected from a bullet by the overlying layers of fat. Two important examples of formal logic are used to legitimately simplify the experiment. First, containers of lard are placed in front of a human analogue dummy in an amount corresponding to the

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world's fattest person: if the amount of lard corresponding to the fat possessed by the world's most obese person is insufficient to stop a bullet, then no person's fat can stop a bullet. This logic is also used in choice of the firearms employed. If a round from a 45-caliber gun with the low muzzle velocity of 900 ft/s passes through unimpeded, it is futile to try larger caliber rounds as all have greater penetrating power: "If this makes it all the way through our fat and vital organs, every other kind of round we could fire would as well," succinctly explains Adam. While the syllogism example utilizes mathematical variables and symbols and the myth utilizes containers of fat and the penetrating power of bullets, the principles are the same: "The validity or invalidity of a deductive argument depends on its form, and not on its content" [12].

6. Objectivity

MythBusters effectively communicates the jurisdiction and constraints of science. Science deals with matters in an objective fashion, and it is important that "students develop an understanding of … what science can and cannot do" [14].

Oftentimes, the *MythBusters* are confronted with having to assess something for which there is no obvious way to measure. In the "Beer Goggles" myth ["Alcohol Myths"—OAD: 10/22/2008], the *MythBusters* test the commonly held belief that the consumption of alcohol makes people perceive others as being more physically attractive (**Table 1** Entry 18). Early on, Jamie points out that this myth will be especially difficult to test empirically: "This seems to be a really subjective thing. We need to be objective if we're going to be scientific." In an attempt to quantify an essentially qualitative, subjective choice, the *MythBusters* employ a large sample size and numerically rate dozens of photographs of people while sober and while intoxicated: "The researcher may turn to rating as a last resort, when any more precise and explicit convention for scoring cases is either impossible or is deemed too much trouble" [15].

In the myth of "Taking Candy From a Baby" ["Mini Myth Madness"—OAD: 11/10/2010], the *MythBusters* are confronted with having to devise a method to measure something seemingly subjective in testing the idiom that taking candy from a baby truly is the epitome of effortlessness (**Table 1** Entry 19). They decide to "reduce the myth to a single quantifiable measurement – grip strength" by measuring the amount of force required to take candy away from newborns and infants (consenting parents were present) using a mechanical gripper.

In the "Square Wheels" myth ["Square Wheels"—OAD: 4/8/2012], the *MythBusters* test whether if above a certain speed, square wheels can provide a smooth ride (**Table 1** Entry 20). Testing the "smoothness" of a ride seems like an inherently unquantifiable, unscientific proposition, as Adam notes, "If these [square wheels] have any chance at all of giving us a smooth ride, how are we going to know beyond our own subjective experience? We need an objective measuring system for telling us how smooth our ride is." The *MythBusters* decide to place vibration sensors on the suspension and steering column of their vehicle as well as on the passengers inside the vehicle. After reviewing the data from the vibration sensors, Adam concludes "[T]he data is pretty compelling and it actually seems to match what Jamie and I felt in the truck …"

Oftentimes, the *MythBusters* are confronted with having to assess something for which there is no obvious way to measure. In the "Driving Dangerously" myth ["Driving in Heels"—OAD: 4/29/2012], Adam and Jamie test whether certain types of footwear make driving dangerous (**Table 1** Entry 21):

> *Jamie: "[H]ow do you propose we test them?"*
>
> *Adam: "[W]e each wear a strange piece of footwear with our foot all the way down on the accelerator. Then we time how long it takes to get from the accelerator all the way to the brake."*

In the "Tryptophan Turkey" myth ["Surreal Gourmet Hour"/"Food Fables"—OAD: 11/18/2012], Tory, Kari, and Grant test whether eating turkey makes you sleepy (**Table 1** Entry 22). As sleepiness is inherently subjective, they decide to measure their reflexes by playing a game of Whac-A-Mole. They compare their scores obtained after consuming tryptophan capsules, a turkey-laden meal, and a meal without any turkey but containing the same number of calories.

7. Operational definitions

MythBusters demonstrates the importance of operational definitions in scientific experiments. Operational definitions involve comparison of phenomena of interest against a standard: "Operational definition means defining the phenomena under investigation in such a way that they can be observed and measured, at least indirectly, in terms of other phenomena that can also be observed and measured" [12].

In "Water Heater Rocket" ["Exploding Water Heater"—OAD: 11/7/07], the *MythBusters* test whether a malfunctioning pressure release can cause a water heater to explode through multiple floors of a house like a missile (**Table 1** Entry 23). To ensure the validity of their results, the scale house they create is built to California building code specifications. They rigorously adhere to uniform standards and codes so that they can apply the results they obtain to existing houses.

Many of the myths tested by the *MythBusters* involve explosives. Operational definitions feature heavily in these myths. In the "Bourne Magazine" myth ["Blue Ice"—OAD: 4/13/2011], the *MythBusters* explore the combustibility of different ratios of air and methane gas (**Table 1** Entry 24). In their initial testing, they make use of operational definitions when employing the concept of standard temperature and pressure (STP) in determining the exact stoichiometric ratio of fuel to air that is explosive.

In the "What is Bomb Proof?" myth ["Running on Water"—OAD: 4/20/2011], the *MythBusters* employ Oseco burst disks as a way of determining whether blasts are harmless or would have resulted in injury or death (**Table 1** Entry 25). As the narrator explains, "We've used burst disks before on the show to find out if various shock waves were survivable without actually resorting to a human sacrifice. So in this control blast, they're testing the outer limits of two differently calibrated disks: one set for certain death, the other for injury." Grant

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provides a more detailed description of how these metal foil membranes, calibrated to burst at certain pressures, can be used to infer whether an explosion would have inflicted serious bodily harm or caused death: "We're going to set up a number of radii from the epicenter of the blast. At each of these radii, we're going to put two burst disks: one that goes at 13 [PSI], which is the threshold of injury, and one that goes at 75 [PSI], which is the threshold of instant death."

Operational definitions again feature in the "Let There Be Light" myth ["Let There Be Light"—OAD: 6/22/2011], in which Adam and Jamie test a scene from the movie *The Mummy* that depicts an elaborate system of ancient Egyptian mirrors redirecting light from the sun to illuminate a dark tomb (**Table 1** Entry 26). The concept of operational definitions is introduced at the onset as this excerpt of dialog illustrates:

> *Adam: "[T]his myth is all about lighting up the darkness with the sun's rays reflected. We need to answer the question: What does it mean to light up the darkness?"*
>
> *Jamie: "We need to define that: What's the minimum amount of light necessary to move around in an unfamiliar space?"*

Later in the myth, Adam emphasizes the use of operational definitions yet again: "Before we start bouncing light around … with mirrors, we need to determine a couple of benchmarks that we'll be aiming for in these tests … What is the minimum amount of ambient light required to see?"

The *MythBusters* excel at finding ways inherently difficult to measure and quantify phenomena using operational definitions.

8. Small-scale testing

MythBusters demonstrates the importance of small-scale testing in scientific experiments. It often behooves researchers to experiment with a small-scale model before investing substantial amounts of capital and time in a full-scale version. Technical concerns caught at the small-scale experiment can be remedied before the full-scale experiment is implemented.

In "Down with the Titanic" ["Down with the Titanic"—OAD: 1/25/2004], the *MythBusters* test the idea that a sinking ship generates a vortex powerful enough to suck people in the surrounding water down with it (**Table 1** Entry 27). They start off not by scuttling a boat but rather with smaller proof-of-concept tests using an aerator (bubbler) and hydrometer in a swimming pool.

In "Bubble Trouble" ["Bubble Trouble"—OAD: 4/27/2011], the *MythBusters* test whether it is impossible to swim in bubbly water (**Table 1** Entry 28). They begin with a small-scale test involving an aquarium tank and aerator along with a hydrometer to measure the density of bubbly water. This small-scale test yields a surprising result, with the *MythBusters* finding that the decrease in water density is offset and counteracted by the upwelling current of bubbles.

In "Wrecking Ball Baloney" ["Newton's Crane Cradle"—OAD: 10/5/2011], Adam and Jamie test an internet viral video of a giant Newton's cradle (a classic tabletop demonstration of elastic collision and energy transfer) made from wrecking balls set in motion by a crane at a construction site (**Table 1** Entry 29). The *MythBusters* decide to approach the myth cautiously rather than rush headlong to replicate the viral video:

> *Adam: "How do you want to proceed?"*
>
> *Jamie: "[S]ince this is all about scaling the Newton's cradle effect … why don't we do it gradually?"*
>
> *Adam: "You mean incrementally bumping up the size of our Newton cradles?"*
>
> *Jamie: "Exactly, and see if we can tease out any kind of problems dealing with the increase in scale."*

Later, Adam reiterates the rationale for implementing a small-scale version of the experiment first: "Before we go to full-scale, we're going to try a scale experiment with the simplest arrangement possible … it … ought to give us a good guide as to the viability of our concept for the large-scale one."

In the "Square Wheels" myth (previously discussed), Adam and Jamie test whether it's possible for square wheels to provide a smooth ride to a vehicle. They conduct small-scale tests involving a model vehicle on a treadmill to elucidate which wheel configuration gives the smoothest ride. This setup serves to provide crucial data on which configurations lead to dangerous resonance effects that might shake a vehicle apart at the full scale. As Jamie explains, "Our small-scale tests showed that the best configuration was to have two opposing corners with their points down, the opposite two corners with their flats down. That balances things out the best and so that's what we're going to do full-scale."

In "Tablecloth Chaos" ["Tablecloth Chaos"—OAD: 10/27/2010], the *MythBusters* attempt to replicate another internet viral video that purports to show a quickly accelerating motorcycle being used to whisk a tablecloth free of a fully laden banquet table without disturbing a single place setting (**Table 1** Entry 30). Adam decides to start with small-scale testing for obvious reasons: "We're going to scale this up to a fairly impossible dimension and I suspect that a lot of factors – object heaviness, cloth type, table type – all of these things – might affect our success on that scale. Thus, in the small-scale, we need to learn what factors are critical to making it work."

The use of small-scale, proof-of-concept testing features prominently in myths involving explosives. In "Surfing with Dynamite" ["Lead Balloon"—OAD: 1/23/2008], the build team conducts a small-scale demonstration before detonating dynamite in a quarry lake (**Table 1** Entry 31). Using plastic bottles filled with subliming dry ice, they test wave generation at the surface of a pool while varying the depth of the explosion. This small-scale test tells them at which relative depth explosions create surface waves with the greatest amplitude. As the narrator explains, "So the guys have their proof of concept; an explosion will make waves and depth is a factor in the size and quality of those waves."

In "Drain Disaster" ["Drain Disaster"—OAD: 11/2/2011], Adam and Jamie test whether a methane gas buildup in a sewer system can ignite and launch manhole covers skyward (**Table 1** Entry 32). Again, the *MythBusters* choose to begin at the small scale. As Jamie explains, "[B]efore we lock in on a full-size plan, let's do a small-scale one first and see if we can learn anything."

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In "Valkyrie Boom" ["Operation Valkyrie"—OAD: 12/22/2010], the *MythBusters* test whether a last-minute change of venue from an underground bunker to an aboveground conference room prevented an attempted assassination of Hitler from proving fatal (**Table 1** Entry 33). Adam decides to start with a small-scale test to illustrate the difference between an explosion in a closed space, such as a bunker, and in an open space, such as an aboveground room with windows. In his small-scale test, Adam visualizes the wave mechanics by dropping weights into a tank of water. From the behavior of the ripples in water, Adam is able to collect evidence in favor of the myth that allows him to confidently proceed to the full-scale experiment.

In "Trench Torpedo" ["Trench Torpedo"—OAD: 10/14/2012], the *MythBusters* test whether, in World War I, building trenches with abrupt, right-angle corners served to prevent shock waves from exploding artillery shells from propagating (**Table 1** Entry 34). Adam starts exploring this myth at the small scale with wave tanks of different geometries: straight with abrupt, right-angle corners and with gradual, rounded corners. From this small-scale test, Adam finds a definite reduction in the amplitude of ripples in the tank with right-angle bends, lending credence to the myth and supplying the evidence needed to proceed with the full-scale experiment.

9. Interpretation of results

The *MythBusters* convey the intrinsic conservatism of science by not making sweeping generalizations or unjustifiably extrapolating the results they obtain: "[S]cientists and educators must resist the urge to state the case of science in terms that are stronger than the data support" [16].

In the myth of "antigravity" (previously discussed), the build team arrives at a conclusion of busted: "So anti-gravity is busted," Kari summarizes. This prompts Tory to retort, "I don't know if we can bust anti-gravity. I mean we can bust our devices." To which Kari replies, "Alright. Revised. Anti-gravity busted … for now." This exchange demonstrates how scientific explanations are tentative and that the current understanding of a phenomenon may not be the final word on the matter [17, 18].

In "The Haunted Hum" myth ["Fright Night"—OAD: 10/28/2012], Adam and Jamie test whether an infrasonic hum may be responsible for peoples' perceptions of certain buildings as being haunted (**Table 1** Entry 35). In this experiment, the *MythBusters* select four identical cabins in the remote woods as an appropriate venue for the myth. They apply the auditory stimulus in only one of the four cabins. They have participants spend 2 minutes alone in each cabin and report which cabin they found to be most unsettling. Most participants in the experiment found the first cabin to be the most unnerving, while the infrasonic tone was applied in the third cabin. As Adam concludes, "Ten tests. Ten test subjects. And I think we can definitively state that cabin 3 – the sound we put through it – did not make it the spookiest cabin. If anything, cabin 1 was the spookiest cabin, cabin 4, the least spooky. Now this could be because of one of two reasons. Either, because we had everyone enter the cabins in numerical order, the newness of the experiment and the weirdness of sitting alone in a room for two minutes made them the most frightened at the beginning and the least frightened at the end. The other reason is that cabin 1 could actually be haunted. But I don't think so." In this

way, Adam masterfully demonstrates how scientists are cautious and conservative in drawing conclusions from their experimental data. The *MythBusters* excel at identifying alternative explanations to account for a finding: "Even a statistically significant relationship must not be taken as supporting a causal hypothesis unless all plausible alternative explanations for the observed statistical relationship have been eliminated" [12].

10. Repeatability of results

One central tenet of science that is often omitted from the classroom is the importance of repeatability. The essence of science is that any result should be able to be reproduced on demand: "We do not take even our own observations quite seriously, or accept them as scientific observations, until we have repeated and tested them … Only by such repetitions can we convince ourselves that we are not dealing with a mere isolated 'coincidence'" [19].

In science, one person or team publishes its findings, and other people or teams seek to recreate the results. If the same materials are used and the same conditions are observed, then the results should be the same regardless of who conducts the experiment or where it is conducted: "The essence of the scientific method lies in the repeatable result: if you perform an experiment in the same way, nature will do the same thing again. This is the heart of science and is the sign that an observable phenomenon in nature has been found" [20]. This is what sets the scientist apart from seer, shaman, and oracle who purport to have a unique ability unable to be taught or communicated to others.

Lack of repeatability is often the deciding factor in the collective rejection by the scientific community of a new claim.

In 1977, SETI (Search for Extraterrestrial Intelligence) astronomers at the Big Ear radio telescope at Ohio State University picked up an intensely strong, narrowband radio signal. The unique nature of what was dubbed the Wow! signal seemed to imply an artificial (intelligent) origin, but because the signal did not repeat, the existence of extraterrestrial intelligence could not be confirmed.

In 1989, scientists Stanley Pons and Martin Fleischmann claimed to have achieved cold fusion: the fusion of heavy hydrogen at room temperature. The claim caused a global sensation, promising to usher in an era of cheap, clean, limitless nuclear power. However, the inability of others to obtain the same results quickly led the scientific community to excoriate cold fusion proponents [21]. Indeed, the failure of other scientists to reproduce the results claimed by Pons and Fleischmann dealt a credibility blow so severe that the entire field has never recovered and is even today looked upon by the overwhelming majority of scientists as little more than alchemy.

The importance of repeatability is frequently emphasized on *MythBusters*. As the narrator reminds the audience, "Reliable results should be repeatable" ["Running on Water"—OAD: 4/20/2011]. This point is succinctly communicated in the "Primary Perception" myth (**Table 1** Entry 36) ["Deadly Straw"—OAD: 9/6/2006]. The build team tests the myth that plants are conscious and capable of exhibiting emotions, such as fear and anger, detectable

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by polygraph. When subjecting plants connected to bioelectrical monitoring equipment to physical abuse, the build team initially obtains some startling results that seem to indicate that the myth has some validity. However, upon further testing, they are unable to duplicate the surprising results. This prompts the *MythBusters* to classify the myth as busted, with Tory concluding, "If you can't repeat it, it's not science."

11. Summary

Educators must use all tools at their disposal, including television, to improve their students' understanding of the scientific method and instill in them an appreciation of its wide-ranging versatility. Understanding the scientific method and how to use it is more widely applicable and transferrable than the accumulation of disparate facts that can be recalled on a whim [22–25]. While formal student assessment was not conducted, feedback (via informal conversation) showed increased student confidence in identifying experimental controls and greater appreciation of the importance of controls in experiment design following the classroom activity we designed to introduce the scientific method utilizing myths from the show. *MythBusters* communicates the scientific method (proposing a hypothesis, designing and carrying out an experiment, etc.) along with its lesser-known components of experimental controls; the importance of logical reasoning, objectivity, operational definitions, small-scale testing, and interpretation of results, and the importance of the repeatability of results: "If the decades ahead produce another Thomas Edison or Steve Jobs, odds are that he or she will have grown up watching *MythBusters*" [3]. Educators are encouraged to familiarize themselves with the show, starting with the episodes mentioned herein. These episodes can be purchased on DVD from the Discovery Channel website. They can also be downloaded individually or by season from Apple's iTunes Store for immediate streaming.

12. Postscript

After a run of 14 seasons and 282 episodes, the *MythBusters* finale was aired in spring 2016; however, reruns continue to air on Discovery Channel's sister network The Science Channel [26]. In addition, the Science Channel has announced that it is relaunching the show with new hosts to be determined through its new reality show *Search for the Next MythBusters*. Also, build team members Tory, Kari, and Grant will be investigating unusual events from pop culture, science, and history in the Netflix original *White Rabbit Project*. Lastly, a hands-on exhibition with artifacts from the show, interactive exhibits, and live demos called "*MythBusters*: The Explosive Exhibition" was installed at the Mall of America in Minneapolis, MN, in 2016 and at the Liberty Science Center in Jersey City, NJ, in 2017. With reruns, a reboot, a spin-off, and a touring exhibition, the final pedagogical legacy of *MythBusters* is not yet written.

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