Students Engineer Tools for Scientific Discovery via Empirical Research on the Mach Field

Peter Mark Jansson PE PhD, Bucknell University

Abstract – This paper summarizes a summer of empirical research completed by undergraduate electrical engineers who desired an experience of engineering beyond the classroom by grappling hands-on with the tools of scientific discovery. In addition, the research focus of their investigations required scientific equipment use, application of new data capture technologies, revisions to new scientific equipment and significant data analyses and interpretation. In this first summer research for the student team, they also realized how exciting and engaging it can be to develop relevant technical and professional skills that will make them more valuable in a future workplace or research setting. The core focus of their research experience was to attempt an independent validation of scientific discoveries being published by others – and purported to be evidence of a Mach-like inertial reaction force which could be detected when high inertial masses are in the presence of significant alignments of solar system and near-universe mass. While this work does not focus on the significance or debates relative to the merits of the science and evidence for such discoveries it provides a unique platform for students to gain intimate knowledge regarding the methods of scientific discovery, the development and implementation of experimental protocol, the application and modification of test equipment, data analyses techniques, programs and technologies as well as a host of other experiential learning useful to practicing engineers and researchers. These experiences, while difficult to provide time for in the classroom, are uniquely suited to open-ended scientific research and implicitly include motivation for the students since they feel part of the process of gaining skills for scientific discovery – one of National Academy of Engineering Grand Challenges categories. The students successfully replicated some of the controversial findings being published by others.

Background

Most of the engineering professors working in higher education as well as members of ASEE know about the Grand Challenges in engineering established by the National Academy of Engineering. What might not be as familiar to many of them is one of the challenges known as "Engineering the Tools of Scientific Discovery" In the summary of this challenge provided on the NAE website [1] one can read the following: "In the popular mind, scientists and engineers have distinct job descriptions. Scientists explore, experiment, and discover; engineers create, design, and build. But in truth, the distinction is blurry, and engineers participate in the scientific process of discovery in many ways. Grand experiments and missions of exploration always need engineering expertise to design the tools, instruments, and systems that make it possible to acquire new knowledge about the physical and biological worlds. In the century ahead, engineers will continue to be partners with scientists in the great quest for understanding many unanswered questions of nature.… All things considered, the frontiers of nature represent the grandest of challenges, for engineers, scientists, and society itself." As one considers many of the recent important discoveries from nanotech to gravity waves described on the referenced NAE website one cannot help but observe how critical the role of engineers as well as the technologies they create impact discovery. The work described in this paper is one more example of how engineers create technology and conduct empirical investigations with it, just like scientists, to observe the interactions occurring in the natural world. The electrical engineering students involved in this story were charged with seemingly mundane tasks of completing significant data analyses of work completed by others [2] as well as attempting independent interpretation of the results. Key reviewers of the controversial work up until that point identified improvements in the technology that must occur for the device and associated experiments to be considered good science. This led the students to apply new data capture technologies and make careful, measured revisions to the scientific apparatus involved. Finally, all of this applied engineering led them to empirical investigations (performed independently of the original researchers) which validated the previous scientific discoveries. [3-4] This paper focuses not on the results themselves (except indirectly) but more on the actual experiences that this empirical research provided to the students that enabled them to develop tools for scientific discovery themselves. These activities included: developing first-hand, intimate knowledge regarding experimental protocol (a key method of replication critical to scientific discovery), the development, implementation, application and modification of scientific test equipment, sound data analysis techniques, working with computer programs and sensing technologies, and finally how the overall challenge for their independent work resulted in experiential learning typically unrivaled in the 50-min classroom sessions and typical 2-hour laboratory pedagogies available in our engineering students' educational milieu.

The Challenges

As previously described, engineers participate in the tasks of scientific discovery in many ways. These include the design of better sensor equipment and arrays, in data collection systems and the computational algorithms that analyze such collected data. In our students' summer research experience, it was not much different. The challenge we faced as a research team included multiple requirements. The feedback that we had received from earlier presentations of the results of experiments made it clear that in order for a larger portion of the scientific community to be interested in the potential "discovery" apparent from the empirical results we would have to increase repeatability, move to real-time data collection and assure that there were no alternate explanations that could account for the observed results. This was a very tall order given that the students were hired to work on the research only over their two summer months of availability. As a result of our initial prioritization of what could be achieved, the team was focused on three primary main areas for their investigation. First, they would gather all previous research results and view each of the experiments (> 100) with their fresh eyes and critical minds. Whenever they had sufficient data from the lab notes available to them, they would perform independent analyses of the raw data to apply voltage rebound calculations (which would help the data be assessed on a common framework – these calculations account for the battery voltage change during the time between the end of the experiment and when the battery voltage measurements were made after the experiment.) This would enable them to look for patterns or solid hypotheses as possible explanations of the findings. The need to assure a common base was a comment we received from scientists when we presented the results of our work at Aerospace Corporation [5] in November 2017. In order for the reader to understand the benefit of these calculations, they may wish to consult the experimental protocol and its revision over time via references 2-5. To describe that detail here would be a digression from the role we are exploring in the students' experimental investigations and learning experiences. In order to best understand the process of scientific discovery, the students had to become intimately familiar with what the experiments entailed. What were the underlying assumptions and how would the detailed protocol support testing these assumptions? What could be expected to happen, what should happen and what would indicate that something novel was being observed or recorded by the experimental protocol? Before the summer research experience, the students had not been engaged in meticulous, protocol-based empirical investigations requiring detailed data collection before, during and after each experimental run. This process was explained to them as one of the key foundations of the scientific empirical enterprise and a core competency they must develop and hone in order to document any scientific discovery. It would therefore be an excellent way to begin by understanding how repeatable empirical experiments can be when a rigorous protocol is established and followed.

Second, they were charged with modifying and updating the experimental Mach Field Detector device to make it a more effective sensor. The device is shown in Figure 1 below. The two main

Figure 1 – Mach Field Detector

areas here included: testing the internal impedances of the wiring of the series and parallel strings of sensor batteries to minimize variances and to find optimal means to integrate real-time data logging into the device. Prior to their work, all voltage data was collected manually (pre- and post- experiment) and little had been done to measure the varying impedances possibly being created along the multiple paths of power flow. Also no components had been active on the device to enable real-time data collection and experimental observations. When the research team tested the eight (8) series strings, they found significant variability among the resistances of each path. They set about to correct that through re-wiring each arm of the device with larger conductors while focusing on producing good connections (for wires and battery holders). The series string impedances were also lowered by reducing the overall length of the wires where possible. Forty (40) measurements were run to test the impedance of each arm and to calculate the average impedance of each arm and the mean of all 8 arms. Each arm's impedance was found to be within 2 sigma of the mean. With a decreased impedance of the device, the experimental protocol was adjusted (i.e., by reducing the starting voltage of the experiment, since the DC motors would now receive more current more quickly). The team worked next to best understand what the options were to add real-time voltage measurement to the device. While considering budget limits and research time available to them, they specified, procured and installed two new data loggers on the detector. They chose DATAQ Model DI-1110 which enabled them to collect and store real-time voltage measurements during the experimental runs across the top 2 series batteries and the bottom 4 series batteries on each of the detector's arms. As will be seen later, this system provided critical insights into what actually was happening when the significant events occurred. The ability of scientists to improve their experimental protocol and devices based upon the input, criticism and ideas of other scientists was also a critical part of the pathway to scientific discovery. By making these improvements to the device (and the associated protocol changes), the team advanced the state-of the-art for the Mach Field detector.

Finally, the team was asked to conduct completely independent trials, to analyze their results, and summarize their associated data. The need for independent replication of any major new discovery in science is a critical step in the forward progress of knowledge. To be able to predict reliably how and when something can and should happen is a key part of the establishment of the reality of a scientific phenomenon. The team was encouraged to not only work on their own through the protocol and experiments but to realize that from their professor's point of view all accurate observational results were desired. They were impressed that the goal was not to validate the work of the previous researchers but to prove (whether positively or negatively) whether the hypothesis that local and near matter could be counted on to interact with the inertial experiments of the detector in a way that could be repeated and demonstrated to interested observers.

Results

The summer research engineering students were successful on all counts. They were able to summarize the previous data (collected by the experiments by others) to verify that for each previous experiment where there were significant outliers that they were associated with a large mass alignment. They completed and tested their major improvements to the device that had been recommended by other scientists. Their rewiring led to more device efficiency and beyond real-time voltage measurement they added a current shunt resistance, connected in series from the power supply to the device, which now allows real time current measurements to be made during the experiment. The protocol they followed was a significantly modified version of that used in the previous research. Control trials are now defined as the experimental trials that are run when the local space (in the vicinity of Earth, the solar system and nearby galaxies) does not present significant mass alignments. Experiments testing the effect are run with significant (or what is currently believed to be significant) alignments of these near masses are observed. Otherwise, the same rigorous testing protocol used in previous work including similar analysis methods developed by the previous research team members is employed. Table 1 indicates that the researchers observed additional outliers (of statistical significance) over their summer of research in 2018. This work adds an additional 2 experiments where statistically significant (> 4 sigma standard deviations), large magnitude (> 40 mV) outliers were observed to the list of ten (10) previously recorded.

Table 1 – Mach Field Detector Results (2000 – 2018)

Date/Device	Type of Anomaly (Sigma)	Deviation mV from mean	Celestial Bodies Potentially Involved Above/Below Earth
29 Feb 2000[1]	3 Battery polarity reversals	2150, 1490, 1190 mV	Virgo supercluster, (M-W Black Holes)
1 Mar 2000[1]	1 Battery polarity reversal	1433 mV	Virgo supercluster, (M-W Black Holes)
1 Oct 2016[2]	17-36 σ outlier	593 mV	Virgo supercluster, Moon, Sun, Venus, Mercury, Jupiter
1 Oct 2016[2]	15-32 σ outlier	533 mV	Virgo supercluster, Moon, Sun, Venus, Mercury, Jupiter
1 Oct 2016[2]	8.8-18 σ outlier	303 mV	Virgo supercluster, Moon, Sun, Venus, Mercury, Jupiter
29 Oct 2016[2]	5.9 σ outlier	66 mV	Virgo supercluster, Moon, Sun, Jupiter, Mercury
29 Oct 2016[2]	4.7 σ outlier	51 mV	Virgo supercluster, Moon, Sun, Jupiter, Mercury
23 Apr 2017[2]	5.5 σ outlier	61 mV	Moon, Sun, Venus, Mercury
21 Aug 2017[2]	-8.2 σ LO & 18.8 σ HI outlier	-106 mV & 177 mV	Moon, Sun (during Eclipse) – Excluding Echo Arm from Std Dev calc.
------ Apparatus Elevated from Subterranean Laboratory to 1st and 2nd floor Labs			
19 Oct 2017[2]	4.0 σ outlier	51 mV	Virgo supercluster, Moon, Sun, Venus, Mercury, Jupiter
30 Jun 2018[3]	4.8-6.8 σ outlier	159 mV	Under Earth - Moon, Mars, Saturn, Jupiter, M-W Black Holes
15 July 2018[3]	4.5-5.6 σ outlier	45 mV	Virgo supercluster, Moon, Sun, Mercury, Jupiter
AVERAGE OUTLIER DEVIATION FROM MEAN		***561 mV***	

Device Designation: [1] – 12 battery device in Cambridge UK, [2] – 48 battery device in Lewisburg PA USA, [3] – 48 battery device with real-time data logging in Lewisburg, PA USA

Further, the students became the first to discover how the voltage effect manifests itself over the course of the experiment. Their real-time data collection system enables the research team to observe when the effect occurred and the abruptness of the interaction, which is consistent with some of the earliest observations of the device. The graphic in Figure 2 illustrates how powerful the addition of real-time voltage sensing during the course of an actual experiment can be. The red arrow points to the 'E' Arm battery pack voltage which has experienced a significantly different discharge characteristic then the other arms experiencing a similar electrical load. The location of the Arm in question is directly facing the Earth in the test apparatus and directly beneath the Earth at the time of this experiment were a grouping a significant solar system planets, the Moon as well as the Black Holes at the Center of the Milky Way Galaxy (Blue box shown on Figure 3). Finally Figure 4 illustrates the significant deviation of one of the E Arm batteries that experienced a large voltage discharge as a result of the experiment (statistically 4.8 to 6.8 sigma from the group experimental mean).

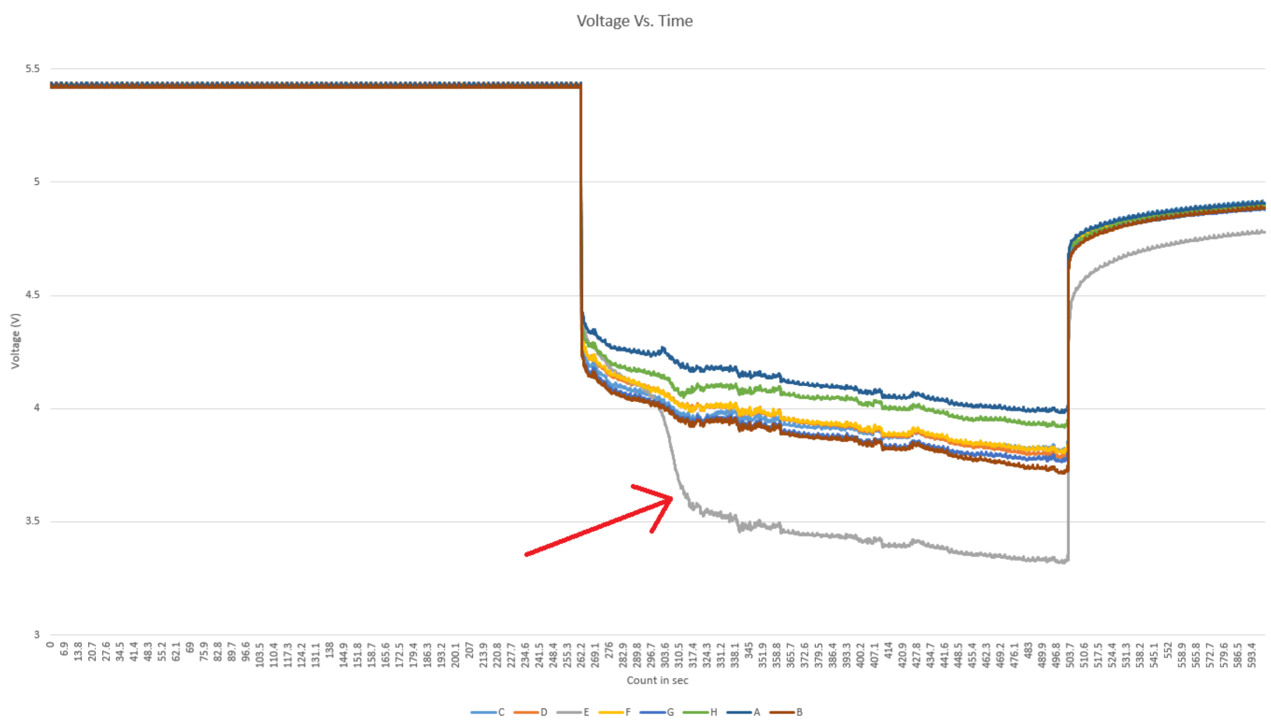

Figure 2 – Mach Field Detector Arm Real-Time Voltages: 30 June 2018

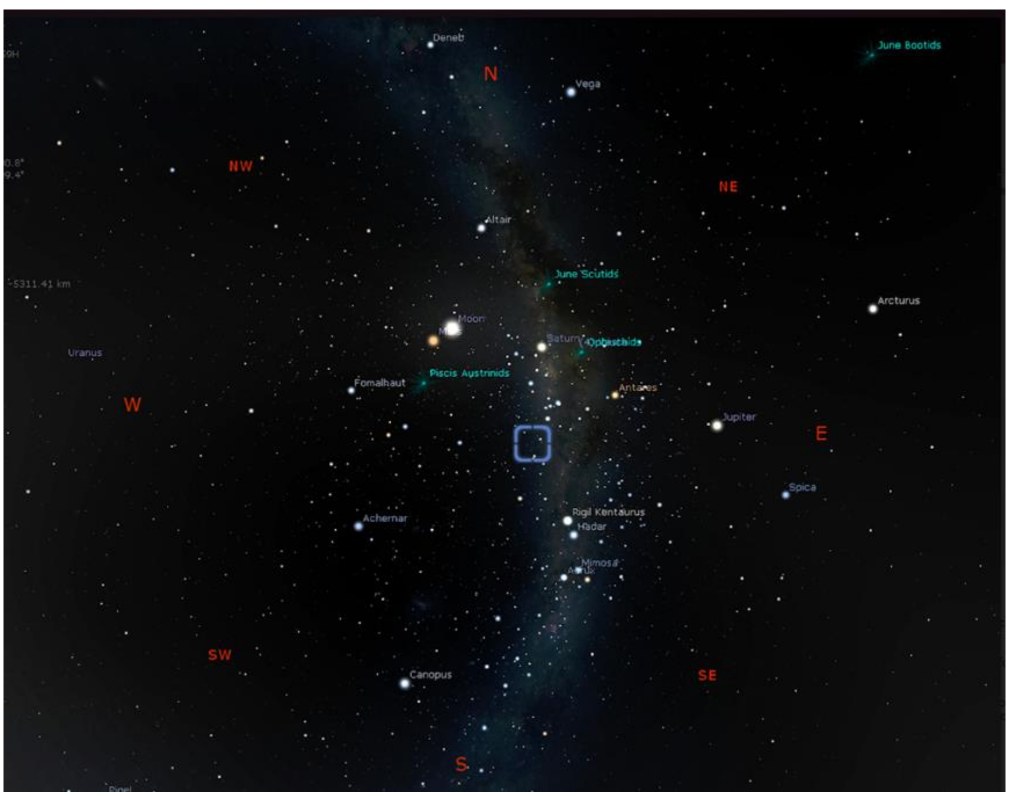

Figure 3 – The Sky Beneath Earth (via Stellarium[6]): 30 June 2018

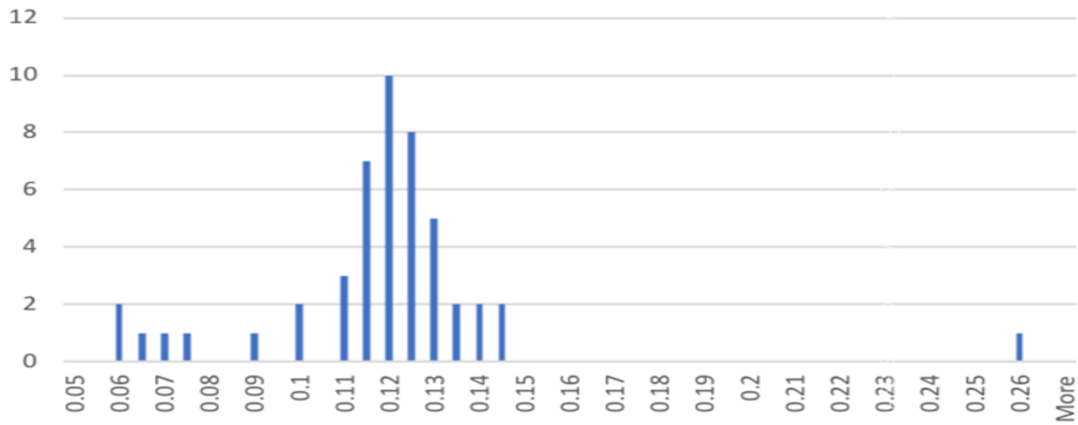

Figure 4 – Detector Arm Battery Voltage Deltas: 30 June 2018

Of great significance in the students' experimental results is that the probability of an outlier of this large magnitude (approximately 5 sigma) happening randomly represents a very unlikely event. The recent gravity wave observations [7] from the Laser Interferometer Gravitational-Wave Observatory (LIGO) is one of the key scientific devices highlighted on the NAE website for the Grand Challenge: Engineer the Tools of Scientific Discovery [1]. In that reference it is referred to as the amazing device "which measure waves of gravity rippling through space", and that is a remarkable achievement which rightfully earned it the Nobel Prize in Physics in 2017. LIGO scientists were able to verify that the gravity wave was "real" and not "a fluke" because it stood out from the background noise with a sigma of 5.1, meaning there is "only 1 chance in almost 6 million that the result is a fluke" [8]. Our research students are joining in the publication of our findings [see References 3 and 4] so that other scientists can undertake the work of replicating these results that are now becoming more compelling as each new observation validates that this is a reproducible phenomenon.

Student Researchers' Feedback

During the course of the summer research experience the author anecdotally was convinced of the growing confidence and independence of the student research team. In addition, it surely seemed plausible that this type of hands-on, open-ended research experience may be a method to building curiosity and developing a strong foundation in engineering students for life-long learning. As the students were objectively surveyed and asked to comment on their research experience and give specific feedback to their professor it became more likely that this was actually the experience of those on the team. Though not statistically significant (as it is only a team of two individuals), the fact that both experienced a perceptible increase in their self-management of research by this summer experience and both grew in their desire for life-long learning is worthy of mention. The survey questions and the researchers' self-reported before and after scores are shown in Table 2 below:

Table 2 - Researchers' Assessment of Self-Management & Life-long Learning (Pre & Post)

To what degree were you able to self-manage the research at the beginning of the summer research experience?: (1 - needed much guidance, 3 - needed some guidance, 5 - no help required) - please select:	
1 2 3 4 5	**RESEARCHERS' RESPONSE Range: 1-2**
To what degree were you able to self-manage the research at the END of the summer research experience?: (1 - needed much guidance, 3 - needed some guidance, 5 - no help required) - please select:	
1 2 3 4 5	**RESEARCHERS' RESPONSE Range: 4**

To what degree did you have a strong desire to continue lifelong learning at the beginning of the summer research experience?: (1 - had limited or no curiosity of discovery, 3 - had some curiosity for discovering new things, 5 - my curiosity has always been boundless) - please select:	
1 2 3 4 5	**RESEARCHERS' RESPONSE Range: 3**
To what degree do you now have a strong desire to continue lifelong learning after your summer research experience?: (1 - still have limited or no curiosity for discovery, 3 - have some curiosity for discovering new things, 5 - my curiosity has been greatly increased) - please select:	
1 2 3 4 5	**RESEARCHERS' RESPONSE Range: 4-5**

Some self-reported student researcher comments are also worth highlighting here. When asked if and how this open-ended summer research opportunity may have complemented their engineering education Researcher 1 stated: "Overall, this summer learning opportunity was an extremely valuable part of my education experience. I learned so much about "real" engineering. I learned to look at problems, devise solutions, and then implement them to solve the problem. A lab that you do in class usually has 1-2 solutions to a problem, so to have a problem that could be solved in many ways was an interesting learning experience. I would highly suggest this to future students because it opens up the door to what you could possibly be doing in real-life. Summer research was a great challenge, especially with how open ended it was, forcing me to take control of a project, not just follow a set of instructions." Researcher 2 reported: "It is for sure a valuable part of my educational experience at Bucknell. In the research, I was left with a broad open ended project that posed some challenges that I needed to deal with in some way that was not taught in class or written in a textbook (i.e.: increasing the precision of the device by decreasing overall resistance, figuring out how the protocol should be modified to fit the new adjustments, making and following our own decisions, deciding between an experimental trial and a control trial), analyzing previous results by looking at them from different views, trying to find and justify connections between the new results and the previous results, etc.) Also, the research made me feel like I am in an official real job because I had to work every day from the morning till the end of a workday, taking a lunch break in its official time." When asked if they could comment on how the experience helped them develop self-management during the summer Researcher 1 said "I felt that at the beginning you gave us a laundry list of possible things to accomplish over the summer and then we had to begin tackling them. By the end of summer, it was more like we were running our own experiments and deciding for ourselves what we wanted to do next." Researcher 2 responded as follows: "In the beginning, I did not know how or when to conduct experiments and did not understand exactly what we were looking for; towards the middle of the summer, all of these concerns were settled and the remaining queries were a matter of marginal concerns (i.e.: adding adjustments to the device, changing the protocol, fixing the motors, and deciding on whether some experiments were worthy alignments to do an experiment for or not)." It is clear to the author that these candid responses are indicative of a real and positive change in researcher confidence and self-motivation. To move from a situation where one is ready, willing and able to do what is required of them, to devising methods for modifying, improving and optimizing an experimental device and protocol and determining for oneself the next appropriate steps in continuing the progress of the research program is a significant shift. The impacts of this summer research experience seem to have been far greater than producing some very important and significant scientific results.

Conclusions

The tools in the toolkit employed by scientific discovery are many. The roles engineers will play in developing and using those tools in both big scientific endeavors (such as LIGO) and small science experiments (like those described here) will be diverse and significant. A recent article in in the Harvard Business Review describes the dominance of large research teams in how science is performed today "while solitary inventors, researchers, and small teams have all been on the decline." But in stark contrast to that statement, their review of "millions of papers, patents, and software projects… found that while large teams do indeed advance and develop science, small teams are critical for disrupting it."[9] That may actually be one of the least thought of tools for scientific discovery, the work of small teams gathering new empirical data that challenges the status quo of science like the work described here. The skills that the students developed over their summer experience are at the foundation of the scientific method and discovery. They learned to understand experimental protocol (and to revise it as needed) and to use and revise new scientific equipment; these skills are applicable to life beyond university in industry, academe or consultancy. Their design and application of new data capture technologies and the significant data analysis and interpretation associated with real world investigations will serve them well in their remaining years as students and their careers beyond. During this research, the student team worked independently, provided regular communications of status and progress and learned how exciting it can be to work on scientific discovery. They know that these experiences helped develop skills that will make them successful in future workplace or research settings. They developed goals for the future research teams to come after them, (such as modifying the data collection system to have all 48 batteries monitored singly in real-time, along with the electrical current). Demonstrating they learned the value of continuous improvement. The experiences created in the research environment challenged them to apply their engineering education, taught them to self-manage and instilled a strong desire to lifelong learning. So many of these and similar learning outcomes are desired in the normal classroom and lab settings, but the opportunities that discovery-driven research experiences provide to students to enhance both the depth and breadth of their learning are multitudinous.

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