AC 2012-3464: NAVY METROLOGY ENGINEERING EDUCATION OUTREACH: INSPIRING AND EDUCATING STUDENTS ABOUT CAREERS IN METROLOGY

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Navy Metrology Engineering Education Outreach: Inspiring and Educating Students about Careers in Metrology

Abstract:

The Navy's Metrology and Calibration (METCAL) Program is essential to effective operations, important to the Navy's acquisition processes, and critical for proper and effective equipment maintenance and repair. The Navy could not operate effectively without a sound METCAL system in place. The Navy's Metrology Engineering Center (MEC) and associated laboratory has a continuing need to hire engineers and scientists to engage in executing and maintaining the Navy's METCAL system that supports the Navy worldwide. Unfortunately, it is extremely rare to find a graduating engineer or scientist that is aware of metrology. Typically, the only exceptions are graduates who have served in the military or worked as technicians before attending college.

Metrology, or the Science of Measurement, is not a commonly known career field. In fact, metrology is seldom studied or discussed at any level of public or private education from grade school through college. The Navy's Metrology Engineering Center and Measurement Science and Technology Laboratory has been involved in numerous partnerships and activities in an effort to educate students, teachers, professors, and counselors at all levels in the educational system about metrology as a career field. MEC's STEM Outreach activities have been used to spread the metrology message along with partnering with colleges and universities.

This paper will discuss many of the efforts that MEC has used to educate people about the field of metrology. The essence of the Navy Metrology and Calibration Program including its vast laboratory structure are provided as a foundation to illustrate skill sets and disciplines involved generally with metrology. Then, MEC's partnerships and other activities to educate people about metrology and to inspire students to consider metrology as a career field are presented. Also, specific examples of projects with professional societies and other organizations involved with metrology are highlighted and discussed. Included are MEC's various STEM outreach efforts highlighting metrology that align with DoD's STEM Outreach Strategic Plan as well as partnerships developed with local colleges and universities. The intent of the paper will be to provide a basic understanding of metrology as an important career field, show ongoing efforts to educate students about metrology, provide some examples of existing basic metrology resource material, and inspire discussion about including metrology in early engineering and science classes as well as an available career field.

Introduction/Background:

The Navy Metrology Engineering Center and Gage and Standards Laboratory (now consolidated into the Measurement Science and Technology Laboratory) are located at the Naval Surface Warfare Center, Corona, CA (NSWC Corona Division). This Metrology Engineering Center and associated Laboratory are designated as the Navy's Metrology and Calibration (METCAL) Program technical agent and provide for all of the Navy and Marine Corps Test and Measurement Systems (TAMS) research, development and engineering support. NSWC Corona

Division employs over 1,500 engineers, scientists and technical support personnel directly and through support contracts with over 250 employed in the metrology and calibration field to execute the central technical agent responsibilities for the Navy's METCAL Program. The engineering capabilities required to be sustained in order to perform this important function span a multitude of disciplines from electronic/electrical (both high and low power), mechanical, microwave, chemical, pressure, temperature, and physical/dimensional to name a few. Further, engineering expertise must be maintained to handle emerging technologies as well as those that were fielded as far back as 40 years ago, but remain in today's military. In essence, the engineering talent must be maintained across both the time domain as well as the technical discipline domain in order to adequately execute the mission of providing full life cycle support for all Navy and Marine Corps TAMS. Newly hired engineers and scientists often have no background or understanding in metrology; thereby, requiring further training after employment in measurement science disciplines in order to supplement their basic education in engineering and science specialties. Typically, the only exceptions are graduates who have served in the military or worked as technicians before attending college.

Metrology, or the Science of Measurement, is not a commonly known career field. In fact, metrology is seldom studied or discussed at any level of public or private education from grade school through college. Metrology is often confused with meteorology, but the two are radically different disciplines. Meteorology is the most familiar term and involves study of the weather. Metrology is the science of measurement. Many are unfamiliar with the term even though there exists a large national and international community of engineers and scientists that work in the metrology field. Metrology is often paired with the term "calibration" since calibration is the process whereby measurement devices are compared and their accuracies are adjusted. Metrology and calibration serve as the backbone of a sound measurement system whether at the international, national or local level. The international and national systems of measurement are nested in a hierarchy of measurement standards that are routinely compared to assure that measurements taken in any system are traceable and accurate to nationally and internationally maintained standards. All other measurement systems whether maintained within a company or by a state or within the Navy link into the national measurement system and maintain traceability to the national and international standards. Developing, maintaining and advancing these measurement systems, whether at the national, international or local level, is the job of the metrologist.

History of Metrology:

Metrology and calibration systems can be historically traced back to the earliest of times. One of the most cited examples of a metrology and calibration system that was in use during ancient times was the one used in the building of the great pyramids in ancient Egypt. It is believed that about 3,000 years B.C., the Egyptian unit of length was established. The Royal Egyptian Cubit was decreed to be equal to the length of the forearm from the bottom of the elbow to the tip of the middle finger plus the width of the palm of the hand of the ruling Pharaoh at that time. This length was carved onto a solid piece of black granite to endure for all time and was known as the Royal Cubit Master. Workers building tombs, temples and pyramids were supplied with cubit sticks made from wood or granite. The Royal Architect or foreman of each construction site was responsible for transferring and maintaining the unit of length to the workers cubit sticks. It was

required that the cubit sticks be brought at each full moon to be compared (or calibrated) to the Royal Cubit Master. Penalty for failure to have the wooden cubit sticks calibrated was punishable by death. The use of the cubit sticks provided standardization and uniformity of all length measurements. This measurement system allowed for the construction of the pyramids with remarkable accuracy. In fact, the Great Pyramid of Giza was constructed to stand roughly 756 feet or 9,069.4 inches. Using cubit sticks and this calibration system, the builders came within 4.5 inches which equates to an accuracy of 0.05 %.[1]

From these early times, metrology and calibration systems have advanced into the measurement system in place today. Although we all have become reliant on having standardization and uniformity in measurements, this does not occur on its own. An active scientific and technical community maintains and advances our international and national systems of measurements. Global trade and all societies rely on sufficiently accurate measurements to support commerce, manufacturing, maintenance, construction, diagnostics, trade and many other activities that we take for granted in today's world. Although this paper is not intended to provide the complete details and history of the world of metrology, it is useful to provide a basic understanding of metrology so as to see the breadth and significance of metrology as a career field. A very general discussion of metrology basics will be presented followed by using the Navy's METCAL Program as an example of the practical aspects of an active metrology and calibration system in use today.

Metrology and Calibration Basics:

Metrology is defined by the International Bureau of Weights and Measures (BIPM) as "the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology."[2] The ontology and international vocabulary of metrology (VIM) is maintained by the International Organization for Standardization. Metrology is an extremely broad field, but may be generally divided into three main subfields: (1) Scientific or fundamental metrology, (2) Applied or industrial metrology, and (3) Legal metrology. Scientific or fundamental metrology concerns the establishment of quantity systems, unit systems, units of measurement; the development of new measurement methods and techniques; realization of measurement standards; and the transfer of traceability from these standards to users in society. Applied or industrial metrology concerns the application of measurement science to manufacturing, construction, maintenance and other important processes used in society to ensure the suitability of measurement instruments and provide for their calibration and quality control of measurements. Legal metrology concerns regulatory requirements of measurements and measurement instruments for the protection of health, public safety, the environment, consumers and fair trade as well as enabling taxation of goods based on measures such as weight or volume.[3]

A core concept in metrology is measurement traceability, defined by the BIPM as "the property of the result of a measurement or the value of a standard whereby it can be related to stated references usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties."[4] The level of traceability (that is, how far up or down the measurement chain) establishes the level of comparability of the measurement: whether the result of a measurement can be compared to the previous one, a measurement result taken a year

ago, or to the result of a measurement performed anywhere else in the world. Traceability is most often obtained by calibration performed in a laboratory which establishes the relation between the indication of a measurement instrument (such as test equipment) and the value of a measurement standard with known accuracy. These measurement standards are maintained in standards laboratories which are usually coordinated by national metrological institutes such as the National Institute of Standard and Technology (NIST) in the United States and the National Physical Laboratory (NPL) in the United Kingdom. The national metrological institutes maintain their traceability to the international standards maintained at BIPM in France. Traceability, accuracy, precision, systematic bias, and evaluation of measurement uncertainty are all critical parts of a quality management system.[5] Metrology has thrived at the interface between science and its application in manufacturing, defense, aerospace, medicine and a multitude of areas that rely on metrology to translate theoretical science into mass produced and maintainable reality.

It is through the interconnectedness and sustainment of metrology and calibration laboratories that the metrologist's output product has its greatest impact. Metrology laboratories are places where both metrology and calibration work are performed while calibration laboratories generally specialize in calibration work alone. Both metrology and calibration laboratories must isolate the measurement work performed from influences that might affect the measurement such as temperature, humidity, vibration, radiated energy, and other influences that can have a negative effect on the measurement at hand.[6] It is, therefore, important to highlight the laboratories when trying to explain metrology. The science of measurement can be quite complex, but its ultimate application is clearly observed in a calibration laboratory. In general, the metrologist determines and develops the measurement systems, processes, procedures and laboratory structure necessary to provide accurate and traceable measurements for use in assuring that the test and measurement equipment relied upon in a program provides accurate and reliable test results. The Navy's METCAL Program which follows will provide a concrete example of this.

Navy METCAL Program:

The Navy Metrology and Calibration Program is generally illustrated in Figure 1 below. The center of the figure is labeled "Test Equipment" and shows a double arrow to the left indicating that the Navy relies on test equipment to perform diagnostics, maintenance, acceptance tests, and provide performance data for all of their Acquisition Programs for new ships, submarines, airplanes, weapons and high tech equipment developed and procured for in-service use. In addition, test, monitoring and diagnostic equipment are used to perform maintenance, adjustments, diagnostics and other procedures during the maintenance and operation of all in-service systems and equipment. It is essential that this test, monitoring and diagnostic equipment be accurate within specified tolerances (or accuracies). Inaccurate test equipment can lead to fatal errors that can result in loss of life and failed missions. It is critical that the Navy's METCAL Program ensure that accurate and reliable test equipment are used throughout the acquisition process and in the operation and maintenance of in-service systems.

Accurate and reliable test, measurement and diagnostic equipment (TMDE) is provided through use of metrology engineering and maintenance of a chain of calibration and standards

laboratories throughout the Navy. The double arrow to the right in Figure 1 indicates that all Navy TMDE is subjected to periodic calibration at the appropriate level in the calibration chain to assure that each piece of TMDE is maintained at its prescribed accuracy. The chain of metrology and calibration laboratories are shown to the right of the figure with the upper most laboratory being our national laboratory (NIST). Below NIST is the Navy Primary Standards Laboratory (NPSL) which maintains its traceability of measurements to NIST and calibrates measurement standards from lower level Navy Calibration Laboratories of which there are several levels not illustrated. Although this depicted calibration chain is simplistic since there are hundreds of Navy calibration laboratories that each require maintaining traceability of the measurements they perform, it serves to show the basic concept. Engineers and scientists in the Navy METCAL Program serve as the technical agent to maintain the accuracy and reliability of measurements within the entire system

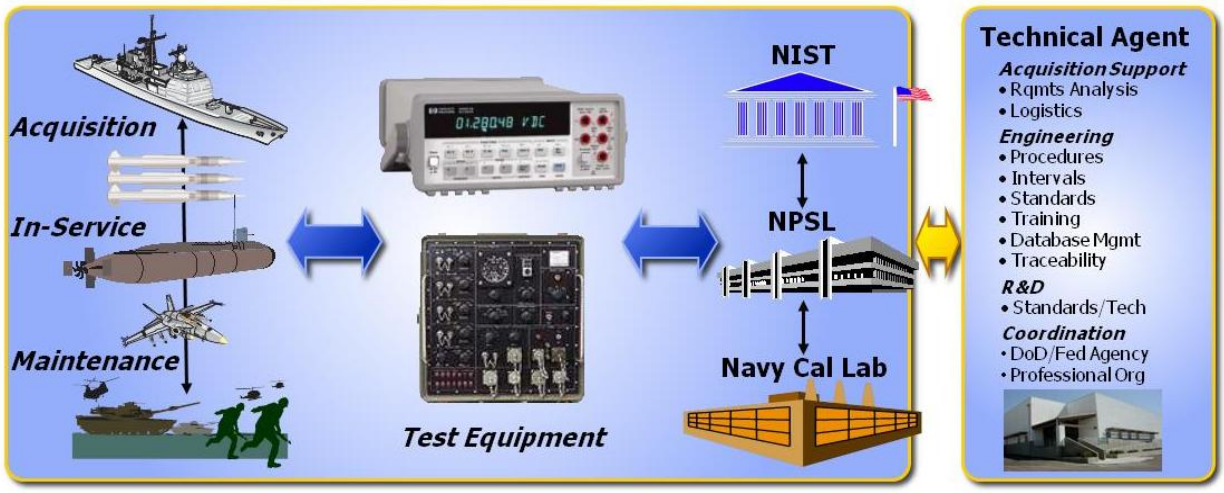

Figure 1. Navy METCAL Program.

Navy metrologists working in support of the various Navy Acquisition Programs perform Calibration and Measurement Requirement Analyses to determine what calibration and measurement support is needed for the TMDE planned for the program. First, a determination is made to assure that the measurement capability is available within the present system. If not, the Metrology R&D Program is often used to develop any needed new capability. These engineers and scientists also determine if measurement support at the right level, right capacity and right locations is available within the present METCAL Program structure (logistics). If not, recommendations and adjustments are engineered to the structure to accommodate the needs of the soon to be fielded systems.

Navy metrologists perform metrology engineering to assure that the right measurement capability is maintained in every metrology and calibration laboratory in the Navy. Measurement accuracy and conformity is maintained by controlling the calibration process in each Navy laboratory to assure that standard procedures and processes are used. This standardization allows the Navy to know that a measurement of a given accuracy made in one Navy laboratory will be comparable to a measurement of the same accuracy in any other Navy calibration laboratory. The calibration process is controlled by prescribing the exact calibration procedure to be used at each accuracy level for every measurement made in every laboratory in

the Navy. This is accomplished through a series of documents and specifications provided to all Navy calibration laboratories along with the collection and analysis of all calibration data coupled with a rigorous calibration laboratory audit and certification program. The controlling documents start with the Instrument Calibration Procedure (ICP) which has the defined process to be followed by any Navy calibration technician performing a calibration on Navy TMDE. The technicians are trained through a common process and are audited for compliance to calibration requirements. Each level of calibration laboratory has a defined set of environment standards (temperature, humidity, vibration, etc) that must be maintained for the measurements they perform. The measurement standards used in every laboratory are prescribed for Navy use and updated through a modernization program through the METCAL Program. A Calibration Problem Report (CPR) system is overlaid throughout the Navy calibration laboratory structure to identify any discovered problem areas to allow for problem resolution. Finally, calibration data for every calibration performed in the Navy is collected and analyzed to determine the calibration Interval necessary to produce the desired measurement reliability. All of these functions are performed by the engineers and scientists in the Navy METCAL Program operating out of NSWC Corona Division. As can be seen, there are many varied metrology tasks and functions necessary to maintaining a large measurement system such as the one supporting the United States Navy. Each of the military services maintains a similar structure, although each varies based on the differences found in the services and their missions. Large companies also maintain fairly sophisticated measurement systems to support their needs. All of these systems link into the national and international standards for traceability of measurements.

The scope of the Navy's METCAL Program is illustrated in Figure 2. As shown in the figure, there are over 400 Navy calibration laboratories performing some 800,000 calibrations annually for about 1.85 million pieces of test equipment. About 5,000 calibration standards are used in these Navy calibration laboratories requiring 5,000 instrument calibration procedures. All of this test equipment, calibration standards, procedures and calibration laboratories require constant review and up-grading to keep abreast of new technologies being constantly introduced through acquisition programs fielding new systems.

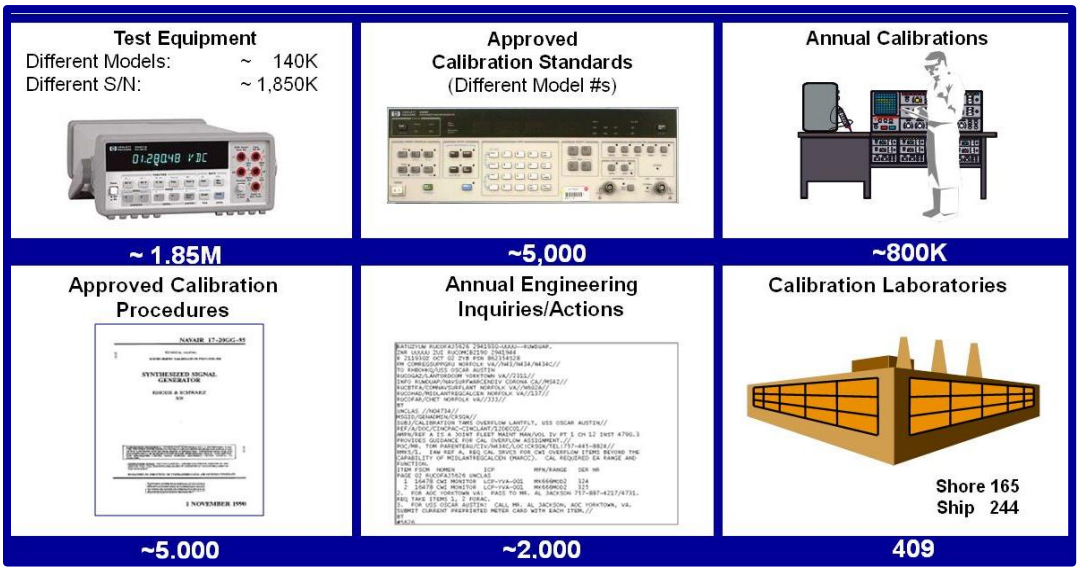

Figure 2. Navy METCAL Program Scope.

Providing the metrology engineering support for such a vast measurement system is a complex and demanding job. As can be seen from the Navy METCAL Program example, there are many varied career options in the field of metrology. Metrology includes robust R&D programs and projects; design and development of measurement systems and instrumentation; metrology engineering support for measurement systems maintenance and up-grades; major acquisition program involvement to determine measurement requirements and logistics; laboratory work; and a multitude of other measurement related jobs are required to provide for accurate and reliable measurements.

Consequences of Measurement Errors:

Even with robust and sophisticated metrology engineering programs in place, measurement errors happen. Some measurement errors merely cost money. For example, when the flow meter that measures how much gas you pumped into your automobile is incorrect, then either you or the gas station owner pays for the error. The same with butcher shop scales that are off and other such errors in measurement during normal commerce. When a measurement error occurs in critical programs, it can be tragic and extremely expensive. Examples of measurement errors in the news are the Hubble Telescope which had incorrect dimensions used in its lens construction. This was not discovered until Hubble was released into space. Later, the lens was corrected to make Hubble useful for its intended purpose. Figure 3 shows tragic results of calibration error.

The impact of a <u>false accept</u> may not be felt until after the end-item is in service.

B-2A, T/N 89-0127
Anderson AFB, Guam
23 February 2008

Cause: False Accept during an air data calibration.

Excerpt from the Accident Report:
"Moisture in the MA port transducer unit (PTUs) during an air data calibration caused an unnecessarily large "bias" or correction to the air data system."

Figure 3. Loss of a B-2A due to measurement error, fortunately pilot and crew survived.

Needless to say, there are many more examples of measurement errors that have resulted in losses of life and property. These examples serve as reminders of the risk of getting the wrong answer when using test, measurement and diagnostic equipment that has not had the full rigor of metrology engineering and calibration applied. It seems that a field so critical as metrology might have a better recognized position and role for their importance to our country.

Background of Metrology Education Outreach Programs, Projects and Partnerships:

As is often advised, it is best to begin at the beginning. In this case the beginning starts with an event in 1995 which caused NSWC Corona Division and its engineering centers to re-evaluate their approach to STEM outreach and maintaining the engineering pipeline. This event was the implementation of the Base Realignment and Closure (BRAC) process. After narrowly surviving the 1995 Base Realignment and Closure round of Department of Defense base closures, NSWC Corona Division and it's Metrology Engineering Center (MEC) and Measurement Science and Technology Laboratory (MSTL) needed a long term strategic approach to providing a pipeline of engineers to replace those lost during the base closure process and a plan to replace the mass of baby boomers approaching retirement in the next 15 to 20 years. NSWC Corona developed a proactive approach to maintaining a pipeline of engineers that involved numerous outreach activities into the local university and college systems and into the local high schools that helped solve more immediate needs of MEC and the MSTL. Like DoD, Corona's Metrology Engineering Center and MSTL had discovered the need to expand beyond the normal STEM outreach activities and into a more collaborative and focused strategy concerning STEM outreach. Included in this strategy was to attempt to educate students and faculty about the importance and basics of metrology to the world around us. Early on, it was important to address the earliest stages of the engineering pipeline which begins in grade school, follow that flow of students through junior high and high school, and remain involved throughout the pipeline into the college and university systems. MEC and the MSTL have been active in several professional organizations focused on metrology and calibration throughout the years. These organizations have become active in education outreach activities to further the profession of metrology. Partnering on education outreach through these organizations has expanded MEC's outreach. These efforts will be discussed below. Again, we will begin at the beginning of the educational pipeline and work forward to show the activities that MEC and the MSTL have pursued to educate on the subject of metrology.

Metrology Engineering Education Outreach Efforts for K-12:

MEC and the MSTL have been involved with STEM outreach through a number of partnership and individual activities. The initial efforts in STEM outreach for K-12 involved inviting local schools out to receive tours of our laboratory facilities. The Measurement Science and Technology Laboratory tours have always sparked interest in the visiting students who witness demonstrations of precision measurements. One popular demonstration involves setting up a dial gage atop a steel bar that is secured to a lab granite table. Students are shown that the mere touching of the steel bar imparts enough heat to measure its "growth" as it expands. Through demonstrations such as this, the importance of metrology becomes apparent as the students learn that the length of a steel bar is dependent upon its temperature. The MSTL contains very impressive precision measurement capabilities including a 100,000 pound dead weight machine that is the most accurate machine west of the Mississippi River and is used to calibrate load cells for the Navy's ballistic missile program, NASA and other high tech programs. The students are provided with the history of measurement from early times and the various examples of applications to important programs as they go to different areas of the laboratory for the various demonstrations.

In 2000, MEC and the MSTL became involved with the Science and Technology Education Partnership (STEP) program which was formed to "Inspire students to pursue educations and

careers in science, technology, engineering and mathematics."[7] The STEP Program provides an annual student and teacher conference for local schools. It targets grades 3 to 8, but also includes a session for high school. STEP provides a science show presented by General Atomics out of San Diego, CA and a high tech expo consisting of local high tech companies that demonstrate what engineers and scientists do in their companies. MEC and the MSTL provide booths to take laboratory demonstrations to these students. The most popular demonstration is a laboratory grade infrared camera that is used to show heat signatures in the body. This demonstration attracted the keen interest of a student several STEP conferences ago who asked if he could visit our laboratory to learn more. To shorten this story, that student ended up using the IR camera in conducting his Science Fair project and wound up taking first place in his age group at the state level. The student is now in the local university studying engineering and works as an intern at MEC. The teacher training portion of the STEP Conference also has been enhanced with a metrology education booth that is provided and staffed by NIST personnel. Metrology materials are provided to teachers for use in the classroom. STEP has had 12 conferences since its inception and serves some 3,500 students and 400 teachers annually. STEP has been exported through MEC to Hawaii through our partnership with the Navy's largest calibration laboratory in Pearl Harbor. STEP, Hawaii now serves some 6,000 students annually. MEC provides its IR camera demonstration and hands out metrology literature and materials.

The Measurement Science Conference (MSC), the National Conference of Standards Laboratories, International (NCSLi), and the Measurement Division of the American Society of Quality (ASQ) have all become active in metrology education outreach. MEC, the MSTL and NIST have all participated in the outreach efforts through these organizations. Two metrology education outreach programs that have developed through this partnership will be highlighted which focus on the K-12 grades. The first is the Metrology Ambassador Program headed by NCSLi with partnering with MSC and ASQ.[8] The Metrology Ambassador Program uses a volunteer force of engineers and scientists from participating organizations to go into the K to 12 classroom and provide a metrology demonstration and discussion. The program also knows that the best way to teach about metrology is through demonstration of laboratory measurement equipment showing metrology principles. Metrology Ambassador "lab kits" were developed and purchased through this program. These lab kits are checked out by Metrology Ambassadors via mail from NCSLi headquarters and are used for in classroom demonstrations. Also, ambassadors discuss the importance of metrology and explain it as a career field. The most recent draft Annual Report of Metrology Ambassadors activities showed that 10,424 students and 1,190 teachers were provided with metrology information through 29 events conducted in 2011. The second program involves the development of a Metrology Careers DVD that was a joint effort by NCSLi, MSC and ASQ. A team of metrologists including NIST, MEC and NCSLi participating company representatives spent about a year developing a DVD that explains metrology and targets the 8 to 12 grade students. The DVD explains metrology, gives examples of careers, covers the educational background you should have to pursue a career in metrology and points to metrology resources. It uses videos and actual people who work in metrology to explain it. When this DVD was first released, it became an instant success. Thousands were distributed to schools, school career counselors, teachers and even to colleges and universities. The DVD was so popular that an effort was funded through the partnering organizations to take the content to the internet. The reader can access this content at: metrologycareers.com and now we distribute a card advertising the website instead of distributing so many DVDs at education

outreach events.

The Department of Defense has recently released a strategic plan on STEM Education Outreach and has established a formal organizational structure with goals and objectives.[9] The Office of Naval Research (ONR) is a significant participant in the DoD Educational Outreach efforts and provides funds to activities to further DoD goals. MEC and the MSTL have applied for and received funds to bring in high school students to work alongside metrologists and in the laboratory on a continuing basis. Although MEC has used college interns for years, this is the first formal effort to bring in high school interns. It required an exception to policy to bring in students under the age of 18 years as paid interns. Unfortunately, it will take some time to get a good understanding of the impact and value of this new intern program. Two interns are currently authorized and local interest has caused a good application pool of local students. Our goal for these high school interns is to excite them about careers and opportunities in metrology and encourage their pursuit of engineering degrees. Since they are paid through the this ONR program, we can educate them in metrology and mentor them without requiring to get work product from them as required from our college interns. We plan to continue to employ these students through our college intern program should they stay on the engineering path. Our experience with college interns has been very good. MSC and the MSTL hire as many as six college interns annually, predominately through a technical support contractor. MEC and the MSTL have hired most (about 90%) of the college interns that have worked at MEC or the MSTL through their last two years of college and received their engineering degrees. They all arrived without knowing about metrology and now are in the career field. We have high hopes that the new high school internships will produce students entering college with not only knowledge of metrology, but a desire to focus their education and studies towards metrology. Perhaps they will be encouraged to seek a metrology based senior project before graduating.

These activities have shown examples of metrology education outreach focused on the K to 12 students and teachers. Having metrology explained early in the educational system provides at least an awareness of measurement science and its importance in our lives. Further, a basic understanding that measurement accuracy and reliability does not "just happen" without a metrology structure making it happen is worth emphasizing. Through educational outreach programs such as those discussed thus far, the students and their teachers that have been exposed to metrology can at least take away an appreciation and basic knowledge that metrology is an active career field that is important for society to function properly. Although a lot of effort and activity has been focused on STEM outreach efforts in the earlier grades, we have little data to show impact. It is not possible to track the progress of students who are minors due to laws and regulations. Therefore, all we can do is track attendance and see how many we have exposed to the metrology discipline. And, as can be seen from the STEP student attendee who ended up excelling at the state science fair, we do have some encouraging examples of success where a student manages to stay engaged.

Metrology Engineering Education Outreach Efforts for Colleges and Universities:

MEC and the MSTL have developed Memorandum Of Understandings (MOUs) and partnerships with local colleges and universities over the years to further metrology education and emphasize its importance. MEC has signed formal MOUs with the University of California, Riverside, CA

(UCR); California Polytechnic, Pomona, CA (Cal Poly); and California State University, Los Angeles, CA (CSU, LA) in an effort to reach into the university system with metrology projects and information. MEC has funded several Metrology R&D Projects at UCR taking advantage of their excellent research capabilities and research laboratories. In addition, MEC has funded metrology projects at CSU, LA over the past few years. MEC and the MSTL provide several internships at these universities as well as at California State University, Northridge; California State University, Fullerton; and several other local area universities. MEC participates in career days and also brings local college students into the MSTL for tours and demonstrations as the opportunity presents itself.

MEC has formal ties through MSC, NCSLi and ASQ to participating colleges and universities that are involved in the metrology field, although few universities have formal instruction in metrology. Besides education outreach into universities by MEC and through partnering organizations in NCSLi, MSC and ASQ; several scholarship opportunities are offered annually to entice college students into the field of metrology. The Measurement Science Conference offers some five scholarships annually to engineering and science students who demonstrate some interest in measurement science. The National Conference of Standards Laboratories, International provides scholarships also. In addition, there are many companies that work in the field of metrology providing instruments, services, and products necessary to test, measurement and diagnostics who offer company sponsored scholarships and internships.

There are more 2 year colleges providing some education and certificates in metrology than 4 year colleges. Below are listed the 2 year and 4 year colleges in the United States known to have some metrology coursework or programs:

2 Year Colleges: Butler County Community College (Butler, PA); Central Georgia Technical College (Macon, GA); Ridgewater College (Hutchison, MN); Madison Area Technical College (Madison, WI); Macomb County Community College (Warren, MI); Monroe County Community College (Monroe, MI); Piedmont Technical College (Greenwood, SC); Rock Valley College (Rockford, IL); and Sinclair Community College (Dayton, OH).

4 Year Colleges: California State, Dominguez Hills (CA); Ohio State University (Columbus, OH); University of Central Florida (Orlando, FL); University of North Carolina at Charlotte (Charlotte, NC); and the University of Oklahoma, School of Industrial Engineering (Norman, OK).

The colleges and universities listed above illustrate the small number known by our metrology community to have some education and certificates in metrology. A future project to try to determine the outcomes from the educational activities across these colleges and universities would be informative, but has not been addressed to date.

Internationally, there are many more universities that have formal instruction in metrology. Some countries even have entire universities devoted to metrology such as France which is home to the International Bureau of Weights and Measures (BIPM). Australia, Brazil, Canada, Denmark, Finland, France, Germany, Italy, Poland, Sweden, and the United Kingdom all have universities with major programs devoted to metrology. Metrology is recognized as an important

career field internationally.[10] There is a clear understanding that metrology is an absolute necessity in order for a country to function and for commerce to operate globally. Although the United States has some educational resources focused on metrology, there is no place in the United States that offers formal degree programs devoted to metrology. It seems that the metrology career field is destined to continue to have to train their own in metrology to satisfy the requirements of this important discipline.

Summary:

Without a reliable and accurate measurement system structure, society cannot function. Commerce, industry, research and development, production, defense, medicine and practically all areas require the solid foundation that metrology provides. This requires that a steady flow of metrologists be made available to continue to engineer and advance the measurement structure that our country and its high technology industries rely upon. It would be highly desirable to recognize metrology as a career field and offer formal, higher level education in metrology in order to achieve this steady flow of metrologists. Many education outreach efforts have been shown that are focused on metrology as a career field. Through our Metrology Ambassadors Program K-12 STEM Outreach activities highlighted above, over 10,000 students and about 1,200 teachers were introduced to metrology this past year. About 40,000 students have been impacted through the STEP Program alone over its 12 year history. The in-roads that have been made into the college and university systems have been spotty as efforts have been primarily either through professional association partnerships or by MEC targeting specific universities on its own initiative. These efforts have had some impact, but this is just a start. MEC and its partner organizations will continue to emphasize the need to offer formal metrology education throughout our vast university and college system as well as introducing metrology in the earlier stages of the education of our students. The goal is to recognize metrology as a career field and to increase the number of educational institutions that offer metrology courses. Perhaps the United States will eventually have metrology embedded throughout the educational process so that it is considered as an important foundation to science and technology.

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