Needed Math Conference Proceedings

NEEDED MATH

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LETTER OF TRANSMITTAL

Dear Colleague,

We are pleased to share the ***Needed Math Conference Proceedings*** with you. The Conference was held on January 12-15, 2018, in Baltimore. Its purpose was to begin to identify the mathematics competencies needed by entry-level STEM technicians to be successful in the contemporary workplace.

The invited Conference participants included mathematics educators and employers and instructors of STEM technicians.

We hope the Proceedings will stimulate further dialogue among educators, employers, policy makers, parents, students, and other interested stakeholders and will spark efforts to *increase the contextual relevance* of mathematics education. We believe that teaching mathematics in authentic contexts will provide students with a clearer understanding of the utility and elegance of mathematics. Doing so will enable them to have a firmer basis upon which to build deeper mathematical conceptual and procedural knowledge and to be more successful in school and in the workplace.

In addition to the Conference Findings and Recommendations. the Proceedings also includes a set of needed math examples provided by employers in the three Conference domains: biotechnology, information and communication technology, and manufacturing technology.

We would like to acknowledge the support of the National Science Foundation (NSF) to this Conference project, in particular the NSF Advanced Technological Education program (grant # 1737946). We deeply appreciate the committed involvement of the conferees and the expert leadership provided by the employers and educators who served as Steering Committee members.

We welcome comments and reactions.

Sincerely,

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NEEDED MATH CONFERENCE PROCEEDINGS

"Much that is taught in high school is not needed, much that is taught in middle school is not learned, and some topics that are needed are neither taught nor learned." — *What Does It Really Mean to be College and Work Ready?* A report from the National Center on Education and the Economy (NCEE), 2013

"When am I ever going to use this?" — *Common question from high school math students*

ABSTRACT

Employers, instructors of technical subjects, and mathematics educators who participated in a three-day conference on January 12-15, 2018, concluded that students' mathematical competence should be strengthened by enhancing their ability to solve problems found in real-world contexts. The Needed Math Conference, supported by the Advanced Technological Education (ATE) program of the National Science Foundation (Grant number: 1737946), focused on bringing to light how mathematics education might better reflect the concepts and skills that are prerequisites for postsecondary education technical programs and for successful employment as entry-level technicians in STEM-related fields, as well as in many other occupations. Adding contextual relevance can demonstrate the utility and beauty of the mathematics students learn. Students who have this experience of studying mathematics in real-world contexts will have a firmer basis on which to build more advanced concepts.

The mission of the National Science Foundation's ATE program is stated in its program solicitation:

With an emphasis on two-year colleges, the Advanced Technological Education (ATE) program focuses on the education of technicians for the high-technology fields that drive our nation's economy. The program involves partnerships between academic institutions and industry to promote improvement in the education of science and engineering technicians at the undergraduate and secondary school levels (NSF, 2018).

This goal is of vital importance nationally if the United States is to remain globally competitive.

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INTRODUCTION

Many students are disenfranchised from mathematics because they do not see how the as they study it in school applies to their everyday lives and future careers. Although we might like all students to be drawn to study mathematics by its elegance, to appreciate its patterns, rigor, and structure, and to learn through its study to think abstractly and reason logically, a curriculum aimed at such lofty goals can result in convincing many students that they lack some innate ability and are thus doomed forever to be "bad at math." The insecurity that this engenders then becomes a self-fulfilling prophecy that endures into adulthood, and mathematics instruction becomes a barrier not only to further education but to career goals as well.

The current K-12 math curriculum and pedagogy all too often produce students who are ill-prepared for employment in the technical workplace. Employers report that, despite studying mathematics in every grade from kindergarten through high school and beyond, the graduates they hire often don't know how to tackle the kinds of problems that typically arise in the workplace. For example, while the "renaissance" in manufacturing is a positive development for the economy, employers surveyed for the Manufacturing Institute's 2015 Skills Gap study reported an obstacle: a "sizeable gap" between the talent they need and what is available in the job market. The respondents – over 450 manufacturing executives – listed math skills among the most serious deficiencies, along with technical and computer skills and problem-solving ability. An analysis of skills gaps in four industries including manufacturing found significant "foundational skills gaps" particularly in applied mathematics (Manufacturing Institute and Deloitte, 2015).

The Needed Math Conference, held on January 12 to 15, 2018, brought together employers in three STEM fields (biotechnology, manufacturing technology, and information and communication technology), postsecondary instructors of technical subjects related to those fields, and mathematics educators. There was consensus among them that there is a significant gap between the math that students are taught, tested on, and retain beyond school and the mathematical skills and abilities they need to solve problems commonly found in real-world contexts and that this likely contributes to the undersupply of skilled workers prepared for successful careers in STEM-related fields. Employers felt there will be a continuing need to revisit math curricula to ensure that they align with the needs of technicians in the 21st century workplace. Anecdotal evidence suggests that the inadequate mathematical preparation among high school graduates is reflected in a gap between the number of applicants for postsecondary training in STEM fields and the number of academic openings available.

The problem is complex, and the solutions to it are correspondingly varied, but the basic recommendation from the Conference is that the mathematics standards, assessments, and curriculum be revisited and revised so as to place greater emphasis on the skills needed to solve the kinds of problems that arise in the real world. Although the Conference participants represented only STEM fields, several of them noted that the kind of mathematical skills useful in those areas – *e.g.,* mathematical modeling, statistical reasoning, and systems thinking – are valuable in many other career paths.

We recognize that implementing the recommended changes will be a complex and challenging undertaking, one that is likely to take years to accomplish and require engaging a great many diverse communities with varying interests and constituencies. Therefore, to support the effort, we recommend placing greater emphasis on contextualized math instruction. We urge an increased focus on topics that support teaching math in context and a corresponding shift in emphasis in the instruments that are used to assess learning. We argue that the current mathematics-for-all curriculum and assessment framework should be augmented by establishing a separate mathematically rigorous pathway based on realistic problems representative of those that many students will encounter after they leave school.

Continuing the dialogue among groups that appear disparate but are united in their greater goals is essential. In an ever-more connected world, there is little excuse for not creating a platform for such communication. This conference could be the seed that grows into a full, easy-to-use communication line among the various groups concerned with math curriculum, teaching/ assessing, and utilization.

Needed Math Conference Overview

The Conference brought together 50 individuals representing three groups: employers (from 10 states), community college and secondary school instructors of technical programs (from seven states), and math educators (from seven states). Three STEM domains were represented at the Conference: biotechnology, information and communication technology, and manufacturing technology. The Keynote Address by Dr. Solomon Garfunkel can be found in Appendix A.

The Conference was organized by its Steering Committee, comprised of ATE Center directors/co-PIs, a former NSF ATE program officer, industrialists, secondary school and community college teachers, mathematics educators, researchers, and education administrators. An external evaluator helped design the Conference logic model and examined the outcomes in relation to stated goals. Domain-based Steering Committee members extended personal invitations to employers of STEM technicians and to instructors who are actively engaged in improving education within their technical fields. The mathematics educators on the Steering Committee invited math educator colleagues who are active and respected members of their professional communities. Some companies even fully supported the attendance of their representatives financially, enabling the Conference to exceed its attendance limit. Appendix B lists the participants and Steering Committee members.

The Conference focus on needed math provoked great interest from all constituent groups. Small- and large-group discussions and debates were lively, given the diverse backgrounds of the participants, but the atmosphere remained entirely collegial, mutually respectful, and focused on outcomes. The Conference agenda and the structures used to “mix and match” the various groups — a “horizontal” grouping of math specialists, content instructors, and employers and a “vertical” grouping around disciplines — are described in Appendix C. This matrix strategy may well account for the congeniality and productiveness of the Conference, which is evident in the Findings section and leads directly to the recommendation on following up by maintaining the cross-disciplinary contacts.

Prior to the Conference, the employers invited were asked to submit examples of workplace problems involving math that they might use to test prospective employees. The 29 needed math problems submitted, which can be found at the end of these Proceedings, were distributed to all participants at the start of the Conference. The participants were then divided into three groups, one for each of the three domains, consisting of employers, mathematics educators, and STEM instructors. Each group reviewed all the problems for its domain using a data collection worksheet, presented in Appendix D, to guide them. The worksheet asked for specification of the problem to solve; the math, process skills, and competencies needed to solve the problem; and suggestions to assist teachers in conveying the needed math concepts in context. Using this common instrument, each group analyzed the examples relevant to its domain and used one or more of them to create a single scenario. The scenarios, which are described in Appendix E, are representative of realistic workplace math problems that are likely to arise in that domain. They are valuable in that they single out math skills that even students who have passed the required high school exams often fail to apply successfully. This can happen because the math that the students were taught did not cover some required skills or because the students have difficulty applying skills that they acquired in school when confronted with applying them in a work setting. A Conference subgroup of secondary school STEM educators suggested that Career and Technical Education (CTE)/STEM pathways should be designed to maximize student engagement using “real-world/industry” mathematics. Those recommendations are included in Appendix F.

The Missing Math Skills Problem

The missing math skills problem is not new, nor has it gone unnoticed. In the United Kingdom, for instance, the highly regarded Cockcroft “Mathematics Counts” study (Cockcroft, 1982) set out to identify the mathematical needs of various types of employment and found some important differences between the ways in which math is used in STEM employment and the ways in which the same math is encountered in the classroom. The Cockcroft report suggested that tests of arithmetical skill play a dominant role in schools, whereas conceptual skills such as spatial awareness, understanding of orders of magnitude, approximation, and optimization are of equal or greater importance in industry and receive far less attention in school.

In the U.S., the Curriculum Renewal Across the First Two Years (CRAFTY) project sought to clarify the rationale for the math requirements at two-year colleges and has published mathematics curriculum and instruction (MAA, (n.d.). Research done by the National Center on Education and the Economy (NCEE, 2013) examined the math needed for popular community college programs in multiple colleges in seven states and found that middle school math topics were most important to preparation for these programs. The study also found a misalignment between what was being taught in community college math departments and the math needed by the students to be successful in the applied programs they were pursuing.

Additionally, prior ATE-funded efforts have attempted to identify needed math skills (several members of the Steering Committee were leaders and/or participants in those projects). Among these efforts were *WorkMap*, developed by the Consortium for Mathematics and its Applications (COMAP), which identified the mathematical reasoning and skills employed in various work settings (Garfunkel, 2009) and the National Center for Optics and Photonics Education (OP-TEC) ATE Center’s review and study guides to help aspiring technicians begin their college studies with adequate math skills (OP-TEC, 2015). The Carnegie Foundation has funded two *Pathways* projects (Statway® and Quantway®) intended to “accelerate students’ progress through developmental mathematics by presenting engaging, relevant, and useful mathematics concepts that students can use in their daily lives” (Carnegie, 2010). The National Research Council’s *The Mathematical Sciences in 2025* examined “the current state of the mathematical sciences and explores the changes needed for the discipline to be in a strong position and able to maximize its contribution to the nation in 2025” (NRC, 2013).

Barriers to Change

A clarion call was heard at the Needed Math Conference, especially from the employers, for teaching math in context using an approach that emphasizes its utility and stresses the application of mathematical models of real-world phenomena and processes from the mixing of solutions to the optimization of a wireless communication system. The question arises then, "Why are we not doing this already?" To understand the answer, we need a little history.

In 1989, the National Council of Teachers of Mathematics (NCTM) produced a set of standards that called for, among other things, the teaching of mathematics through practical applications (NCTM, 2000). Following this initiative, the National Science Foundation funded a series of comprehensive curriculum projects at the elementary, middle, and high school levels to create curricula that embodied these standards. Several of these curricula took a contextual approach. Their publication, however, created a reaction from some members of the mathematical research community, who were concerned, among other things, that talented math students would be disadvantaged, or held back, by the mathematics-for-all approach of the new texts and argued for more traditional approaches.

Despite some opposition, the new curricula enjoyed significant market penetration at the elementary and middle school levels, though much less at the high school level, and the more traditional textbooks continue to dominate in high schools to this day. Following the passage of the *No Child Left Behind Act* of 2001 (USDOE, 2001), every state was required to have a set of state math standards and to test every child every year in grades 3 through 8 and at least once in high school. This created a plethora of tests, curricula, and evaluation standards under which the same student might very well test "adequate" in one state but "deficient" in another.

Enter the Common Core State Standards

The goal of the Common Core State Standards was to create one set of standards for all students across the nation, together with tests to measure student performance. An important concern was to get as many states as possible to accept the standards. While mostly traditional in content, they did mention modeling as one of eight overarching mathematical practices. Despite the fact that it was up to individual states to adopt them, the Common Core standards came be regarded as a "national math curriculum" and this engendered a negative perception in some quarters. However, for the foreseeable future, many states will probably retain the skeleton of the Common Core, and we optimistically believe that the importance of modeling and context-based problem solving will increasingly be recognized.

It should be noted that a fundamental difference between this round of reform and the last one, is that this one has not produced many new artifacts. To date, few new textbooks have been written that fully embody the Common Core, whereas in the 1990s, every grade level could avail itself of several newly reformed texts. The likely result is that when all is said and done, we will still mostly be teaching to new tests that look a lot like the old ones unless there is a concerted effort on behalf of educators, employers, and policy makers to reform mathematics instruction to include experiences for students in modeling solutions to real-world, work-specific scenarios.

FINDINGS

Even in geographic regions of significant unemployment, some STEM employers at the Conference stated that they often found it difficult to recruit employees due to their lack of mathematical skills. In addition, technical programs at many community colleges find that the supply of qualified entrants is inadequate to fill the available openings. There have been previous efforts (NCEE, 2013) to elucidate the reasons for these imbalances. The Needed Math Conference was unusual both in its focus on mathematics education and in its efforts to solicit input not only from math and content educators, but also from employers in technology-rich industrial sectors.

In this context, the most important takeaway from the Conference may be the extraordinary level of agreement among the participants. The mismatch between the mathematics that students learn in school and the mathematical requirements of an increasingly technological workplace can only be appreciated by a multidisciplinary community, hence the rationale for the Needed Math Conference. However, the decision to include three disparate groups – employers, program instructors, and math educators – carried with it the potential for discord. It was possible, for instance, that each group might blame the others for the perceived problem. Remarkably, this did not happen. Individuals who under normal circumstances might never have met each other engaged in spirited but respectful discussions over the two and a half days, and although their experiences and starting points were quite distinct, they reached consensus on a number of key issues. Most encouraging, there was general acceptance of a clear need for continuing cooperation between these groups to address the problem and lively interest in facilitating and enlarging the ongoing dialogue around the value and utility of mathematics in the 21st century workplace.

Finding 1. There is a gap between the typical textbook problem and the problems that arise on the job, even though the underlying mathematics may be the same.

The mathematics problems presented in textbooks and on tests have certain features in common. Being intended to teach and assess specific math skills, they usually involve only one such skill at a time and often make that skill explicit. All the problems presented at the end of a chapter dealing with multiplying fractions, for example, will call on that particular skill. In this circumstance, obtaining a passing grade certifies that a student can solve well-defined problems that evoke the application of specific algorithms. This does not prepare students to tackle the more open-ended and ill-defined problems they are likely to confront on the job. After much in-depth discussion, the conferees agreed that the discrepancy can be traced to the following characteristics of workplace problems:

- Workplace problems often involve unspecified constraints or tradeoffs.
- The problem as presented to the employee may include irrelevant information and may not include all the necessary information.

- The statement of the problem does not typically identify the mathematical concepts or skills required for its solution.
- Mathematically equivalent problems are often presented quite differently in industrial contexts, obscuring the underlying skills needed to solve them.
- The math skills or concepts needed may not have been taught to the employee or may have been taught a long time ago (*e.g.,* in middle school) and never revisited.
- The problem may have more than one solution, and solving it may require choosing among them.

And to make matters worse:

- Arriving at an incorrectly thought-through solution to a workplace problem can have serious consequences, both financial and in terms of safety, for customers or for the workers themselves.

Finding 2: There is a gap between the mathematical preparation many students receive and the mathematical requirements of an increasingly technological workplace.

As Conference employers and other studies have corroborated, it is often difficult for businesses to find math-competent local employees. Some of the mathematics that is required for success in a STEM career is either not taught at all or not taught in a way that helps students retain it to be recalled for later use. These topics include the use of mathematics to model real-world phenomena and processes, statistical reasoning, and data analysis so that entry-level technicians are able to define a problem, find the supporting evidence needed to solve the problem, and define the expected goals and outcomes of the solution within constraints.

In addition, some employers expressed concern that since the traditional mathematics curriculum does not address topics relevant to their industry, it constrains the availability of qualified employees by erecting an artificial barrier to students' quest for the appropriate technical degree or certificate.

Finding 3. Too many students cannot make effective use of technology commonly found in the workplace.

Employers gave the use of spreadsheets as an example of a common technology, found in a broad array of enterprises, which entry-level technicians often cannot use. The mathematics they learn in school should prepare students to apply this ubiquitous tool to organize, display, analyze, and present data and to explore "what if?" questions using numerical models. A related skill, identified by many Conference participants is the ability to estimate mathematical results prior to performing a calculation. A common lament was that many job applicants "can't use a calculator," meaning not that they don't understand how to key in a calculation but that they fail to compare the answer to an estimation-based reality check.

Finding 4. As currently taught and assessed, math education has become a barrier to success for many students rather than the pathway to it.

While many students succeed under the present system and acquire a deep understanding of, and appreciation for, mathematics, the Needed Math Conference recognized the existence of a large number of students for whom math has decidedly negative associations.

Summary

The issues raised by the Conference are not new. Significant initiatives have been undertaken to address the problems, yet they persist. Ultimately, ensuring the mathematics preparedness and competency of STEM technicians is the shared responsibility of all stakeholders. To effect real change and improvement, each community has an important role to play, and collaboration among all stakeholders: employers, instructors, mathematics educators, and parents must be ongoing.

RECOMMENDATIONS

Recommendation 1. Place greater emphasis on contextualized math in- struction at all grade levels and in all mathematics courses.

The rationale for teaching mathematics in context is two-fold: such instruction is vital for preparing students to solve practical real-world problems and it improves retention of the very mathematical concepts that constitute the learning goals of the current system of instruction. A voluminous body of research in mathematics education (COMAP, 2017; NCTM, 2000; Johnson, 2002; Larson, 2017; Olkun, 2003; Winkel, 1997, 2016) confirms that many students struggle to learn new abstract concepts because they seem unrelated to other bodies of knowledge with which they are acquainted. For those students, mathematics becomes understandable only when its applications are made explicit.

Recommendation 2. Make a shift in emphasis in the assessments that students must take.

This recommendation follows the one above, which calls for modest but important changes in the mathematics curriculum. Such changes cannot take place without corresponding changes in how mathematics achievement is assessed. Assessments should be driven by the open-ended, flexible, creative problem-solving that is encountered in the real world. They should include items that call for expertise in the areas of mathematics described in Recommendation 3. Assessments not grounded in authentic problems lead to an undervaluing of skills relevant to the workplace. It is not easy to score, much less to create, items that test complex problem-solving ability, but rising to this challenge is seen as central to effecting the changes that are needed.

Recommendation 3. Increase the focus on topics, approaches, and pedagogy that better reflect the demands of the contemporary workplace in all mathematics courses.

Due to the growing availability and importance of data, the conferees agreed that more attention should be paid to teaching topics, approaches, and pedagogy in mathematics that are central to analysis of data—*e.g.*, probability, graphical representations, mathematical modeling, the ability to communicate effectively mathematically, and descriptive statistics.

Although the Conference focused on technical content, the mathematics content we are advocating for is useful across a broad variety of occupations. Data analysis, for instance, is an increasingly important skill for the social sciences, and errors in policy occur because policy makers do not properly apply statistical reasoning. Thus, teaching mathematics in the context of practical problem solving can not only prepare many more students for STEM careers, but also improve mathematics instructions for everyone.

Recommendation 4. Augment the current *mathematics-for-all* curriculum and assessment framework by establishing a separate rigorous pathway from the traditional trajectory, based on solving real-world problems representative of those that students may encounter after they leave school.

1. The current one-size-fits-all math curriculum fails students in two ways: opportunity to pursue higher education or entry into technical careers.
2. By failing to emphasize those aspects of mathematics most relevant for the solving of real-world problems, it fails to prepare many students to succeed in an increasingly complex technological world.

The separate pathway would not be any less challenging than the traditional one, and we do not recommend "tracking" students from an early age. Instead, we envision a more democratic approach wherein a wider variety of math courses are available to secondary school students, who would then be free to make choices based on their interests and intended career paths. We might also envision offering a middle school math course that exposes students to both pathways, so they can use that experience to inform subsequent choices.

The new pathway would contextualize real-world applications of a more restricted body of mathematical knowledge. Thus, a modeling course would almost certainly include models of change over time but would not include a detailed exposition of derivatives and integrals as measures of such change. The calculus course, in contrast, would cover the chain rule for differentiation, but might stop short of implementing and exploring numerical models of change.

In support of this recommendation, a study undertaken by one of the employers at the Conference (Wallace, 2018) indicates that school personnel in New Mexico are very interested in finding an alternative math pathway for many students that does not require Algebra II and the Algebra II PARCC for high school graduation and would like to see project-based learning integrated into high school mathematics courses utilizing many real-world applications pertaining to business and industry.

> According to a report in Policy Analysis for California Education:
>
> Evolutions in various disciplines and in learning sciences are calling into question the relevance and utility of this [mathematics for all] trajectory as a requirement for all students. The emerging movement is toward differentiated "math pathways" with distinct trajectories tied to students' goals. Alternatives emphasizing statistics, modeling, computer science, and quantitative reasoning that are cropping up in high schools and colleges are beginning to challenge the dominance of the familiar math sequence (Burdman, 2015).

Recommendation 5. Create a Needed Math Center charged with expanding the reach of the Conference findings to additional stakeholders by holding follow-on conferences on relevant topics and publishing articles aimed at a wide variety of audiences including policy makers at the state and federal levels.

An important aspect of the Conference was the creation of a multidisciplinary group of educators and employers focused on addressing what was universally perceived as a significant mismatch between the mathematical concepts that most students learn in school and the mathematical skills required for successful performance in the STEM workplace. However, the momentum and energy generated by a single event are unavoidably temporary and easily dissipated. This highlights the need for continuing to support the dialog between mathematics educators, instructors of technical subjects, and employers across a wide range of industrial sectors.

Accordingly, we recommend that the National Science Foundation, in concert with professional organizations such as the American Mathematical Association of Two-Year Colleges, establish a Needed Math Center focused on supporting and sustaining an active community of interest including business and industry representatives, state and local educational agencies, professional organizations, and representation from secondary and postsecondary mathematics programs to provide a forum for improving the mathematics preparedness of STEM technicians entering the workforce.

Among the issues that the center might address are the following:

1. The center could examine the existing mathematics standards to determine the degree of overlap between the math that is taught and the math that is needed.
2. The center could advocate for changes in the math that is taught, how it is taught, and how learning is assessed.
   - Changes in content might include, for instance, an increased focus on common themes like mathematical modeling and reasoning under uncertainty.
   - Changes in pedagogy could place more emphasis on contextual learning and instruction customized to students' needs and interests, rather than treating mathe matics as a one-size-fits-all general education prerequisite to programmatic courses.
3. The center could provide support for collaborations, perhaps in the form of periodic conferences between mathematics and programmatic faculties and in consultation with business and industries that hire graduates from their programs. to provide timely, relevant mathematics content in the degree programs
4. The preparation of a skilled 21st century workforce is of interest to groups beyond the education and business communities. The center could engage labor unions as well as federal, state, and regional entities concerned with planning for the changes initiated by technological innovation.
5. In order to prepare mathematics teachers to offer appropriate contextualized instruction, the center might sponsor summer internships with selected local firms. This experience would not only inform their teaching, but also provide them with a persuasive counter to students' perception that they will never use the math they are learning.
6. Through its connections with employers, unions, and professional associations, the center would be responsible for tracking changes in technology of relevance to the workplace and would work to ensure that the mathematics curriculum and professional development keep pace with such changes.

Concluding Remarks

We recognize that much excellent and well-intentioned work has been done over many years and has resulted in heartfelt and innovative approaches to mathematics education. We are hopeful that the work done by the Needed Math Conference participants can inform further reform efforts, as too many students continue to be disenfranchised by mathematics instruction that does not facilitate the development of a growth mindset but rather often discourages them from pursuing further mathematics study.

By emphasizing mathematical modeling in contexts that learners see as authentic, we, as a community, can inspire and assist schools, states, and organizations to implement math curricula that speak to all learners. Our hope is that all students will be engaged in interesting context-based mathematical problem solving that instills a disposition toward appreciating and valuing the richness of mathematics.

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APPENDIX A
Needed Math Conference Keynote Address

Dr. Solomon Garfunkel, Director, Consortium for Mathematics and its Applications

In preparation for giving this keynote I did quite a bit of research. First I called on the NSF Historian (yes, there is such a person). He sent me to the NSF advanced search database, which has reliable information going back to about 1975. There one sees thousands upon thousands of grants with the key words mathematics, education, industry, technicians. There are conferences, reports, industry specific as well as more general addressing the main themes of this meeting. I found articles in the MATH MONTHLY dating to the late 19th century discussing how to present the mathematics needed by 'modern' industry. This is not a new problem. And this is far from the first conference formed to deal with it. But if we do our job right, it should be the last!

What do I mean by that? Look, we must be aware that essentially, we have two systems that by their nature move at different rates, so that even if we 'catch-up' we will soon be out of sync. Imagine that school mathematics curricula delivered exactly what companies needed tomorrow. Where would we be the day after tomorrow? After all, industry needs what it needs and is used to the notion of having to adapt quickly in order to thrive and survive. Curriculum reform in particular and educational reform in general, move at geologic speed (as anyone who ever tried to change a college course catalog description knows all too well). In many ways the situation is even worse for two-year colleges.

A large part of a two-year college's reputation is built on how successful its students are in transferring to an appropriate four-year school, often a large state university. That university has specific criteria for giving transfer credit, which in a mathematics culture often means standard texts for standard courses. So, required math courses are inevitably taught in mathematics departments in two-year schools trying to clone the 4-year school's offerings. And the student going for an associate degree in IT or Biotech or Manufacturing all too often is sitting in those math classrooms alongside the students hoping to get transfer credit, being taught by teachers who know little of their future employment plans and nothing about IT or Biotech or Manufacturing. Moreover, as numerous reports have documented, the mathematics in those courses is often not what they will need in the workplace – and it is almost always taught out of any real context.

An anecdote. As part of my preparation for this meeting I called a close friend and mentor Henry Pollak. Henry was the director of mathematical research at Bell Labs and then Bellcore for over 28 years beginning in the 60's. He told me an interesting story. For a while during the mid-60s Henry was involved with hiring personnel at the Labs, including technicians. For the senior research personnel, Henry added a criterion. He would ask the applicant to tell him of one instance where he/she used mathematics in their daily life. And, independent of credentials, if the person couldn't name such an instance Henry would not hire them. True story.

But the story even more pertinent to this meeting refers to other hires. Evidently for many years Bell Labs hired technicians who received two-year degrees from DeVry University. And according to Henry these graduates were extremely successful at their jobs. In fact, some were so successful that Bell Labs paid for them to go on to four-year schools to get engineering degrees and thus advance their careers. Well, Devry got wind of this and saw a potential revenue stream. They instituted a full four-year engineering degree program themselves in order to take advantage of this new cohort. But two things happened. First the engineering graduates of Devry were not as well trained as those that Bell had been sending to local universities and second the students who graduated as technicians after the new program had been instituted were nowhere near as good hires as in previous years. And so, Bell Labs stopped hiring Devry graduates in either program. I find this an important cautionary tale.

One more story I heard from Henry that also has something to say about our work this weekend. Some of you may be old enough to remember when there were things called telephone coin boxes. For the youth among us you put your dime (or nickel if you're old enough) in the coin slot in order to get a dial tone and make a call, which likely would cost additional coins. Once upon a time it seemed like there was almost one box on every corner. AT&T sent out its drivers on a regular schedule to pick up the coins in the boxes. But there was a problem. Sometimes a box had very few coins in it and hence not worth the driver's time and other times a box might be so full that it couldn't take any more money.

So the math modelers at Bell Labs were given the problem – was it worth it to put into every coin box an electronic probe which would report when a box had enough coins to be emptied and not be too full. It was estimated that these probes would cost 15 cents each to install. And lo and behold after almost a year's worth of work it was determined that yes in fact it would be cost effective to install the probes and adjust pick up routes accordingly. However, this was the real world and the drivers refused to change their routes and their schedules and the probes were never introduced. Another reminder and reality check on our work.

But we need to get back to why we are here and what we hope to accomplish. Our job is not simply to write yet another report to sit unread in math department and government offices or even to write words that find their way into future NSF RFPs. After all we already know a lot of the answers – we know that a great deal of the mathematics technicians need on the job was presented in grades 6-8 – ratio and proportion, formulas, elementary data analysis. We understand that while arithmetic and geometric visualization are presented in the early grades, in the world of work they are used in complex schema and diagrams. We understand that if mathematics is taught and not used it is forgotten. We know that math taught in context works. We understand the importance of mathematical modeling—moving from the real world to mathematical constructs and back—is fundamental to being able to address new situations. We are a knowledgeable group of practitioners. To quote Joan Crawford (cleaned up a bit) this is not our first time at the rodeo.

Yes, we will go through real examples from our industry colleagues and we will identify the mathematics embedded therein. We will spend some time learning each other's language. Perhaps quite a bit of time. We will talk about what we teach and how we try to teach it. We will learn from each other by identifying deficiencies and how we are trying to overcome them both on the job and in the classroom. We will discuss local programs that have been effective and talk about how we might scale them up. If we do this well—and I'm sure we will—we will get a useful snapshot of where we are with hints as to how we might get better.

But I hope we can do more! Because as I said at the beginning we have two systems that are out of alignment and are likely to keep being so unless we can set in place a self-correcting mechanism that can adjust for needed change in a timely way. Figuring out what that mechanism should be and how to implement it seems to me to be a challenge worth working on. And so I look forward to a wonderful, productive, and LAST conference.

APPENDIX B
Steering Committee and Conference Participants

Steering Committee Members

- **Marilyn Barger**, Director, Florida ATE Center, Hillsborough Community College, Tampa, FL
- **Rosemary Brester**, President and CEO, Hobart Machined Products, Hobart, WA
- **Sol Garfunkel**, Director, Consortium for Mathematics and Its Applications (COMAP), Bedford, MA
- **Michael Hacker**, Co-director, Center for STEM Research at Hofstra University, Hempstead, NY (Project PI)
- **Katherine Hughes**, Principal Researcher, American Institutes for Research, Washington, DC (Research Lead)
- **Paul Horwitz**, Senior Scientist, Concord Consortium, Concord, MA (Project C0-PI)
- **Jennifer Lazare**, Biotech Instructor, Anderson High School and Austin Community College, TX
- **Rodney Null**, Professor, James A. Rhodes State College, Lima, OH
- **Gerhard Salinger,** retired National Science Foundation program officer and originator of the ATE program, Albuquerque, NM
- **Lisa Seidman**, former Program Director in Biotechnology, Madison Area Technical College, Madison, WI
- **Gordon Snyder**, Co-principal Investigator, National ATE Center for Optics and Photonics Education, Waco, TX

External Evaluator

- **Deborah Hecht**, Director, Center for Advanced Study in Education, CUNY Graduate School, NYC

Steering Committee Biographies

Marilyn Barger is the Principal Investigator and Executive Director of the Florida Advanced Technological Education Center of Excellence (FLATE) housed at Hillsborough Community College in Tampa. FLATE is funded by the National Science Foundation (NSF) and serves technical education pathways and programs in Florida that support the manufacturing industry. Marilyn has over 20 years of experience developing and delivering STEM curriculum for K-20 students and educators and has initiated long-term, systemic education reforms. Her Ph.D. is in environmental engineering. Marilyn holds a licensed patent in membrane technology and is a registered professional engineer in Florida.

Rosemary Brester is President and Chief Executive Officer of Hobart Machined Products, Inc. She has served as a member of the Governor's Pipeline Committee, Transition Math Project, and numerous industry and community organizations. Rosemary is passionate about convening industry, community, and governmental groups to make the most of small businesses - and in turn deliver benefits to all of those groups. Rosemary holds an AA degree in Business Management from Green River Community College and a Certificate in Business Collaboration from UW Foster Business School, along with numerous manufacturing related certificates from South Seattle Community. She has a passion for aerospace, space and education.

Sol Garfunkel received his Ph.D. from the University of Wisconsin. He taught at Cornell University and the University of Connecticut before founding COMAP (Consortium for Mathematics and its Applications), where he has been Executive Director since its inception. He has directed NSF-funded curriculum development projects, including UMAP, HiMap, and ARISE. Sol was host for the Annenberg/CPB telecourse, *For All Practical Purposes* and founded and administers the Mathematical Contest in Modeling. Sol received the Glen Gilbert Award from the National Council of Supervisors of Mathematics (NCSM) and a lifetime achievement award from the International Society for Design and Development in Education (ISDDE). He served on the Mathematics Expert Panel of PISA.

Michael Hacker, Ph.D., Needed Math Project PI, is Co-Director of the Center for STEM Research (CSR) at Hofstra University. He has conceived, written, and directed 14 large-scale NSF projects focused on K-14 STEM education. During 50 years in education, Michael was a teacher, department supervisor, and university teacher educator. As New York State Education Department Supervisor for Technology Education, he co-managed the development of New York's *Standards for Mathematics, Science, and Technology*. Michael has co-authored six textbooks and numerous journal articles, scholarly compendia, and conference proceedings. He was on the writing team for the *National Standards for Technological Literacy* and is a member of the ITEEA Academy of Fellows.

Paul Horwitz, Ph.D., holds the position of Senior Scientist at the Concord Consortium, a non-profit organization dedicated to creating innovative educational technology for STEM learning. Following research in theoretical physics in universities and industry, Paul has been exploring the application of technology to teaching and assessment. He has worked in a wide variety of discipline areas and with various age ranges, including running projects that taught evolution to 4^{th} graders, classical mechanics and genetics to middle schoolers, and statistics, chaos theory, and relativity in high school. Currently, he directs projects aimed at assessing collaborative problem-solving skills in students enrolled in electronics courses at two- and four-year colleges.

Katherine Hughes, Ph.D., is a Principal Researcher at the American Institutes for Research, and also the Project Director for *Technical Assistance for Advancing Equity in Career and Technical Education*, an initiative funded by the U.S. Department of Education and awarded to Manhattan Strategy Group. Katherine also works as an independent consultant for the Community College Research Center (CCRC) and other organizations. For many years she was the assistant director of CCRC, conducting and overseeing research on a range of topics addressing the transition from high school to college and careers. She has numerous publications, many on dual enrollment programs, and she co-authored the book, *Working Knowledge: Work-Based Learning and Education Reform*. She holds a doctorate in sociology from Columbia University.

Jennifer Lazare has taught biotechnology as a dual credit high school instructor and an adjunct faculty member at Austin Community College for 10 years. Jennifer also serves as the High School Outreach Coordinator for biotechnology education as senior personnel on the ATE Regional AC2 Bio-Link grant. In this role, she manages a statewide mentor network for high school biotechnology teachers, develops curriculum and assessments, and provides hand-on training to teachers and administrators. Jennifer received her Master's degree in molecular genetics and K-12 science teaching certificate from the University of Texas. She holds principal certification and is enrolled in the Ph.D. program for school improvement at Texas State University.

Rodney Null is a mathematics professor at Rhodes State College with 30+ years of teaching experience, ranging from middle school through university. He is a recipient of the American Mathematical Association of Two-Year Colleges' Teaching Excellence Award and former president of the Ohio Mathematics Association of Two-Year Colleges. He was a steering committee member for the *Ohio Mathematics Initiative*. Rod has participated in three NSF-sponsored projects, most recently as PI for *Mathematics Transitions in STEM Education* and has been a program developer and instructor for numerous initiatives focusing on professional development programs for teachers and improving mathematics instruction.

Gerhard Salinger, Ph.D., retired from the National Science Foundation (NSF) in 2014, where he co-founded the Advanced Technological Education (ATE) Program. He continues to be interested in STEM education K-12 and in the impact of ATE on technician education 7-14. Prior to coming to the NSF, he was on the faculty of the Physics Department at Rensselaer Polytechnic Institute. He now lives in Albuquerque.

Lisa Seidman, Ph.D., is a co-PI for Bio-Link, an NSF-funded consortium of biotechnology programs. She received her doctorate in biology from the University of Wisconsin and was a post-doctoral fellow at Yale University and the University of Wisconsin before becoming an instructor in biotechnology at Madison Area Technical College in 1987. Lisa developed a contextual biotechnology math program that was named "exemplary" by the American Mathematical Association of Two-Year Colleges in 2001. She is the lead author of three textbooks: *Basic Laboratory Methods for Biotechnology: Textbook and Laboratory Reference, Basic Laboratory Calculations for Biotechnology, and Laboratory Manual for Biotechnology and Laboratory Science: The Basics*.

Gordon F. Snyder Jr. is past director of the National Center for Information and Communications Technologies and currently a consultant and Associate Director at the National Center for Optics and Photonics Education. He has authored four engineering/technology textbooks and has over 33 years of industry consulting experience. He served as the Verizon Next Step program telecommunications curriculum co-leader and on several technology boards around the United States, including the Microsoft Community College Advisory Council. In 2001, he was selected as one of the top 15 faculty in the country by Microsoft and the American Association of Community Colleges.

External Evaluator Biography

Deborah Hecht, Ph.D., is Director of the Center for Advanced Study in Education, City University of New York (CUNY) Graduate Center. She has been the co-PI or lead evaluator on dozens of NSF and other funded projects, ranging from small programs that focus on a regional group to statewide and national projects designed to impact practice and policy. With over 30 years of experience, she has studied initiatives in a wide variety of areas including youth development, school reform, STEM education, and faculty development. Deborah has a background in applied psychology and uses multi-methods approaches to study innovations within the context of the implementation environment.

Conference Participants (Alphabetically by Domain)

Last Name	First Name	Domain (Biotech, ICT, Mfg)	Group	Affiliation
Hongo	Jo-Anne	Biotechnology	Employer	Genentech and JS Hongo Consulting
Jochem	Adam	Biotechnology	Employer	Morgridge Institute for Research
Kirkpatrick	Bridgette	Biotechnology	Instructor, CC	Colin College
Simpson	Kevin.	Biotechnology	Employer Instructor, CC	Delgado CC/Autoimmune Technologies LLC
Thompson	Debra	Biotechnology	Employer	Asuragen
Subramanya	Sandesh	Biotechnology	Employer	Brhms LLC
Balas	Cathryn	ICT	Employer	Balas Consulting Services
Beheler	Ann	ICT	Instructor, CC	Collin College
Ellis	Peter	ICT	Employer	DIF Design
Stephenson	Scott	ICT	Instructor Secondary	Education Service Center Region 11 Cisco Academy
Taylor	Mark	ICT	Employer	CVS Health
Adams	Kirk	Manufacturing	Employer	American Foundation for the Blind
Davis	Jacquelyn	Manufacturing	Employer	AMI Metals
Horine	Dan	Manufacturing	Instructor, CC	Virginia Western CC
Mason	John	Manufacturing	Instructor, CC	Ivy Tech Community College
Monroe	Nathan	Manufacturing	Employer	Toray Composite Materials America
Simpson	Elizabeth	Manufacturing	Instructor Secondary	Polk County Public Schools
Sweatman	Shannon	Manufacturing	Employer	Southern Manufacturing Technologies
Thompson	Matthew	Manufacturing	Employer	Toray Composite Materials America
Wallace	Blake	Manufacturing	Employer	Process Equipment and Service Co.
Wallace	Jana	Manufacturing	Employer	Process Equipment and Service Co.
Altose	Aaron	Mathematics	Instructor, CC	Cuyahoga Community College
Baratto	Stefan	Mathematics	Instructor, CC	Clackamas Community College
Ferguson	David	Mathematics/ Engineering Ed	Math Educator	SUNY Stony Brook
Getz	Amy	Mathematics	Math Educator	Dana Center
Kimball	Rob	Mathematics	Math Educator	Wake Technical CC (Retired)
Lewis	Matthew	Mathematics	Math Educator	San Jacinto CC, AACC
Robinson	Eric	Mathematics	Math Educator	Professor Emeritus, Ithaca College
Robinson	Stacy	Mathematics	Instructor Secondary	Trotwood Madison High School
Younker	Michelle	Mathematics	Instructor, CC	Owens Community College
Chamberlain	John	Curriculum and Instruction	Instructor	Center for Occupational Research and Development (CORD)
Stone	James	Curriculum and Instruction	Instructor	National Research Center for CTE Southern Regional Education Board

APPENDIX C
Agenda and Conference Organization

Needed Math Conference Agenda

Friday, January 12
4:00 pm
Registration opens in Friendship One Room

5:00 pm
Greetings and Introductions
Welcome: Dr. Gerhard Salinger, Founder, NSF Advanced Technological Education (ATE) Program
Intended conference outcomes
Overview of agenda, discussion groups, data collection, research and evaluation plans

6:15 pm Keynote Address: *A Conference to End All Conferences*
Dr. Solomon Garfunkel, Executive Director, Consortium for Mathematics and its Applications (COMAP)

7:00 pm: **Buffet Dinner**

Saturday, January 13

7:30 - 8:15 am: Continental Breakfast in Bistro 1 Restaurant

8:15 - 9:45 am
Employer Panel: Discussion of needed math with Jo-Anne Hongo, Biotech; Mark Taylor, ICT; Jana Wallace, Manufacturing; and Kirk Adams, Using Math on the Job as an Employee Who Is Blind or Visually Impaired. Dr. Lisa Seidman, Moderator. Q&A.

9: 45 am: **Refreshment Break**

10:00 am
Session 1. Small-group discussions (same domain). Begin to develop ideas to be refined during the conference and presented at Session 7 on Sunday 1:15 pm

12:00 noon: Buffet Lunch

1:00 pm
Session 2. Domains reconvene in larger groups to refine emerging recommendations on needed math. Each domain produces three or more Data Collection flipcharts. Begin to consider these questions:

1. What commonalities did you find in the needed math?
2. With what math do employees have difficulty, and why?
3. Given that technicians have difficulty with these problems in the workplace and given that they studied math for years, what can we do about it?

3:15 pm: Refreshment Break

3:30 – 4:30 pm
Session 3. Groups present Session 2 results on flipcharts. Dr. Gerhard Salinger, Moderator

4:30 – 5:00 pm
Session 3, *continued*. Synthesis. Group discussion of responses to questions considered in Session 2.

5:00 – 6:00 pm: Break

6:00 pm: Buffet Dinner

7:00 pm
Concluding Discussion: What went well. Sunday agenda review. Dr. Deborah Hecht, Moderator

Sunday, January 14

7:30 - 8:30 am: Continental Breakfast in Bistro 1 Restaurant

8:30 – 8:35 am: Reimbursement procedures – Lois Miceli

8:35 - 9:45 am
Session 4. Affinity groups address focus questions:

- **Employers**: With what math do employees have difficulty and why? What guidance can you give to educators? How is the field evolving, and what are the implications for math requirements?
- **Instructors**: Given the constraints of the present system, what would you change with respect to mathematics in secondary school and community college programs?
- **Math educators**: What needed math commonalities and differences (between domains) have emerged? Given that students have difficulty with math after years of study, what can and should we do?

9:45 - 10: 30 am
Session 5. Affinity groups report out

10:30 am: Refreshment Break

10:45 am - 12:15 pm
Session 6. Domain-based groups finalize the work started on Saturday and prepare flipchart presentations

12:15 pm: Buffet Lunch

1:15 – 2:15 pm
Session 7. Presentations from each domain

2:15 -3:00 pm
Concluding Session. Large-group discussion and reflective comments. Potential areas for funding new proposals: Dr. Gerhard Salinger. Framing recommendations, further initiatives, next steps. Paul Horwitz, Moderator

3:00 pm: Farewell

Needed Math Conference Organization

The Needed Math Conference was organized to encourage active participation from all attendees. Presentations to stimulate discussion and frame the conference outcomes were made by NSF Advanced Technological Education program founder, Dr. Gerhard Salinger, and Dr. Solomon Garfunkel, Executive Director, Consortium for Mathematics and its Applications (COMAP).

A panel comprised of employers from the three Conference domains — biotechnology, information and communication technology, and manufacturing technology — described examples of the mathematics that their STEM technicians typically applied in their work. This occurred on the first morning of the conference and provided a backdrop to group deliberations.

Three types of groupings were facilitated by Steering Committee members.

1. To begin, small groups of people from the same domain (employers, community college, and secondary school instructors) introduced themselves, discussed intended conference outcomes, and raised questions. Also at each table were math educators. The facilitators clarified objectives and guided data gathering procedures. The small groups reconvened several times to capture needed math ideas.
2. All participants in the same domain met to discuss and refine emerging recommendations. Each of these three larger groups was facilitated by a domain-based Steering Committee member. The groups developed flipcharts using a consistent template to begin to generalize ideas.
3. Affinity groups of all employers, instructors, and math educators were convened to add their suggestions regarding conference recommendations. The community college and secondary instructors addressed specific issues related to implementation of needed math at their school level.

Large group discussions focused on synthesizing findings and recommendations from domain-based and affinity groups.

This interactive framework resulted in spirited discussion and the development of a collective perspective.

APPENDIX D
Data Collection Worksheet

Check the Conference Domain: Biotechnology ❑ ICT ❑ Manufacturing ❑

Other ❑ (describe) ____

To whom in the group should we address follow-up questions

Name ____ Email _______________________________________

SPECIFY THE PARTICULAR TECHNICAL PROBLEM TO SOLVE

IDENTIFY THE NEEDED MATH FOR THE PROBLEM ABOVE (What math do entry-level technicians need to be able to solve the problem. State what technicians need to do in *behavioral terms* (*e.g.,* employees will model, calculate, estimate, evaluate, decide, analyze).

HOW WOULD THE PROBLEM BE SOLVED BY AN EMPLOYEE WHO IS ABLE TO DO THE MATH?

CLASSIFY THE NEEDED MATH BY DISCIPLINE, CONCEPT, PROCESS SKILL, AND SPECIFIC COMPETENCIES

Mathematics Discipline *(please check):*

Arithmetic ❑ Algebra ❑ Calculus ❑ Geometry ❑ Operations Research ❑

Statistics and Probability ❑ Trigonometry ❑ Other ❑ (describe)
____

Mathematics Concepts:

Process Skills:

Competencies Needed:

At approximately what grade level(s) is this math taught? ________________ Not Typically Taught ❑

For the example you have provided, briefly describe how the mathematics needed is (or is not) addressed within the grades 6-14 curriculum.

Please provide any suggestions to assist teachers in conveying the needed mathematics concept(s) in context (in the math classroom, the discipline-based classroom, or both).

Briefly describe training that companies might provide to assist employees to gain these skills.

APPENDIX E
Workplace Scenarios

Three workplace scenarios were generated by the Conference working groups of employers, mathematics educators, and STEM instructors representing each of the Conference domains: biotechnology, information and communication technology, and manufacturing technology.

CONTENTS

Biotechnology Workplace Scenario

ELISA
(Enzyme-Linked ImmunoSorbent Assay)

Background

Quantitative assays, such as the Enzyme-Linked ImmunoSorbent Assay (ELISA), are designed to measure the amount of a specific molecule present in a sample. Antibodies are the key component of the ELISA. Millions of different antibodies are available to the research community. Each antibody will only recognize and detect a specific target. The target detected by an antibody is known as its antigen. The flexibility and specificity of these assays allow scientists track molecules that would be otherwise difficult to trace. Medical practitioners commonly diagnose disorders by using ELISAs to detect pathogens or discreet substances in blood or other body fluids.

The following scenario concerns an ELISA that is used to determine the level of parathyroid hormone (PTH) in blood samples. In patients suffering from parathyroid disorder, parathyroid glands produce too much PTH, resulting to a calcium imbalance which may lead to bone loss and kidney malfunction. This disorder can be treated surgically by removing one or more of the parathyroid glands. It is critical that a person be diagnosed correctly: a person whose hormone levels are normal should not be mistakenly subjected to surgery and a person whose hormone levels are abnormal should not be left untreated.

Typically, an ELISA is performed in a 96-well plate (Figure 1). A 96-well plate is a plastic holder that contains 96 tiny test tubes, called "wells." The plastic used to manufacture the plate is designed so that antibodies and other proteins stick to it tightly. For the PTH ELISA, antibodies against PTH (the antigen) are manufactured by specialized companies. These antibody molecules are coated onto the bottom surfaces of the wells. A single well that is coated with antibody against PTH is illustrated in Figure 2A. When an assay is performed, wells are filled with samples prepared from patients' blood. If PTH is present in a sample, it binds to the antibodies on the bottom of the wells. Once the PTH has bound, the wells are rinsed with washing solution. PTH complexed with antibody will remain stuck to the bottom of the well while other substances are washed away, Figure 2B. At this point, the PTH-antibody complex is invisible. To allow for PTH-antibody complex detection, a substance is added which will form a color only in the presence of the PTH-antibody complex. The more PTH in the well, the more intense the color that develops, Figure 2C. Finally, the plate is put into an instrument called a *plate reader*, which detects and quantifies how much color is present in each well.

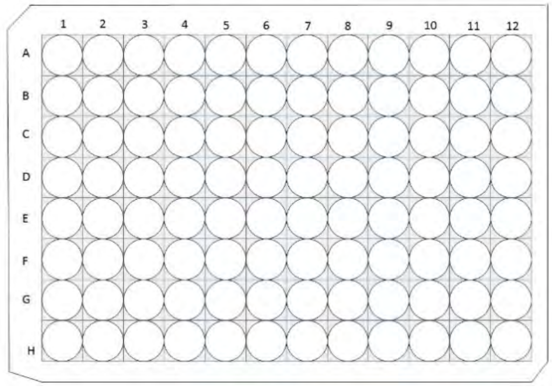


Figure 1. Top View of a 96-Well Plate

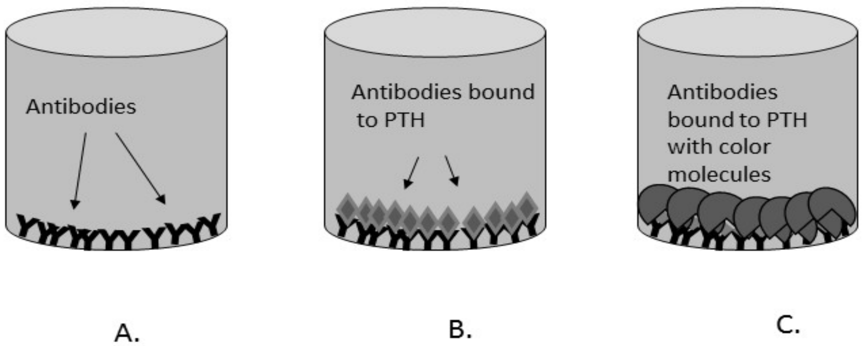


Figure 2. ELISA

2A. Closer view of a single well from a 96-well plate that has been coated with antibody against the PTH hormone
2B. The antigen, PTH, which was present in a sample has bound specifically to the coated antibody
2C. A series of steps were performed resulting in a colored deposit

Recall that this PTH ELISA is *quantitative*, which means it detects not only the presence of PTH, but also *how much* of it is present. It is necessary to understand the concept of a standard curve in order to understand the conduct of a quantitative ELISA. A standard curve is a graph of the relationship between the amount or concentration of a material of interest and the response of an assay. To construct a standard curve for an ELISA assay, the following steps are performed:

Step 1: A series of standards with known levels of the material of interest (in this case, PTH) are prepared by dissolving the material in a water-based solution.
Step 2: A specific volume of each standard is added to its own well of the 96-well plate.
Step 3: The PTH in each standard binds to the antibody that was previously coated on the bottom of the well.
Step 4: The wells are washed to remove extraneous materials, leaving behind the antibody-standard complex.
Step 5: Steps are performed to make the complex colored.

Step 6: The 96-well plate is put into the plate reader, which provides a reading for each well. This reading is proportional to the amount of color in that well. The greater the amount of PTH in the standard, the greater the amount of color is produced and the higher the reading.

Step 7: The resulting readings are plotted on a graph with the concentration of PTH on the X axis and the instrument's reading on the Y axis.

Step 8: The points are connected into a line. This line shows the relationship between the quantity of PTH present and the response of the plate reader. Based on this relationship, it is possible to determine the concentration of PTH in patient samples.

In addition to the standards described above, it is also important to have *controls t*hat indicate whether or not the assay is working properly. *Positive* (**+**) *controls* contain a known level of the material of interest; *negative* (**-**) *controls* contain no such material. If the assay is working properly, it will provide correct values for the positive controls and will not detect any substance of interest in the negative controls. Hence, in this PTH assay, the positive controls contain known levels of hormone; the negative controls, no hormone.

Scenario Example 1

Figure 3 shows a diagram of an ELISA plate that is set up to conduct a PTH ELISA of samples from 3 patients:

- Columns 1 and 2 contain the standards that are used to create the standard curve. Each standard was prepared in duplicate (twice). Thus, the standards in column 1 and column 2 are of the same concentration.
- Columns 3 and 4 contain **+** control samples in replicate. (The negative control is considered to be the same as the first standard, which contains no PTH.)
- Columns 5 and 6 contain patient samples, also in replicate.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
A	Standard 0 ρg/mL	Standard 0 ρg/mL	+ Control 1 30 ρg/mL	+ Control 1 30 ρg/mL	Patient 1	Patient 1 Replicate						
B	Standard 20 ρg/mL	Standard 20 ρg/mL	+ Control 1 60 ρg/mL	+ Control 1 60 ρg/mL	Patient 2	Patient 2 Replicate						
C	Standard 40 ρg/mL	Standard 40 ρg/mL	Control 2 100 ρg/mL	Control 2 100 ρg/mL	Patient 3	Patient 3 Replicate						
D	Standard 80 ρg/mL	Standard 80 ρg/mL										
E	Standard 100 ρg/mL	Standard 100 ρg/mL										
F	Standard 200 ρg/mL	Standard 200 ρg/mL										
G												
H												

Figure 3. Arrangement of Standards, Samples, and Controls in a 96-Well Plate

The assay is performed, and the plate is put into the plate reader. The measured value for each well is shown in Figure 4. The units of measurement are called *AU* (absorbance units). For our purposes, it is not important to discuss the derivation of these units.

	1	2	3	4	5	6	7	8	9	10	11	12
A	0.004	0.001	0.239	0.242	0.550	0.546						
B	0.161	0.153	0.481	0.479	1.344	1.400						
C	0.310	0.311	0.801	0.799	0.037	0.028						
D	0.623	0.626										
E	0.785	0.783										
F	1.569	1.566										
G												
H												

Figure 4. Plate Reader Values for the Standards, Samples, and Controls in the 96-Well Plate Illustrated in Figure 3

The task is to analyze these results. To do so, perform the following steps.

Step 1. Construct a standard curve based on the values for the standards:

- Average the two plate reader values for each standard.
- Prepare a graph with the value of the standard on the X axis and the average plate reader measurements on the Y axis.
- Do the points appear to lie on a single line? If they form a line, connect them into a line. This is the standard curve. If the points appear scattered, consult a supervisor.
- Be sure to label the axes and give the graph a title.

Step 2. Evaluate the results for the positive and negative controls:

- Use the replicate standard with 0 ρg/mL of PTH as the negative control. Average the replicate readings.
- Average the replicate values for the **+** controls.
- Use the standard curve to determine the concentration of PTH in the **+** controls.

The values for the controls should make sense, that is, the plate reader value for the 0 ρg/mL should be zero. Note, however, that there is some noise in readings and the value may be close to, but not exactly, zero. Similarly, the values for the three **+** controls must lie in a particular range. Assume that makers of this ELISA kit specify that the value for the negative control must be in the range of 0 – 3 ρg/mL. The value for the first **+** control must be in the range of 27-33 ρg/mL, the second **+** control must be in the range of 57-63 ρg/mL, and the third **+** control must be in the range of 97-103 ρg/mL.

If the positive and negative controls do not lie in the specified range, DO NOT PROCEED with patient sample analysis but consult your supervisor.

Step 3. If the **+** and **–** controls values are in the specified ranges, then evaluate the patient samples:

- Average the replicate values.
- Use the standard curve to determine the PTH value in each patient sample. Assume that it has been determined, based on previous analysis of many patients, that the normal range for PTH values in this ELISA should be between 23 and 90 ρg/mL.
- Based on this information, evaluate whether each patient's values are in the normal range.

Scenario Example 2
Figures 5 and 6 provide another example with more patient samples. Analyze these results as was previously described.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
A	Standard 0 ρg/mL	Standard 0 ρg/mL	+ Control 1 25 ρg/mL	+ Control 1 25 ρg/mL	Patient 4	Patient 4 Replicate						
B	Standard 30 ρg/mL	Standard 30 ρg/mL	+ Control 1 50 ρg/mL	+ Control 1 50 ρg/mL	Patient 5	Patient 5 Replicate						
C	Standard 50 ρg/mL	Standard 50 ρg/mL	Control 2 100 ρg/mL	Control 2 100 ρg/mL	Patient 6	Patient 6 Replicate						
D	Standard 80 ρg/mL	Standard 80 ρg/mL										
E	Standard 100 ρg/mL	Standard 100 ρg/mL										
F	Standard 200 ρg/mL	Standard 200 ρg/mL										
G												
H												

Figure 5. Scenario Example 2: Arrangement of Standards, Samples, and Controls in a 96-Well Plate

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
A	0.002	0.004	0.988	0.978	0.601	0.603						
B	0.901	0.906	1.505	1.500	1.450	1.440						
C	1.503	1.499	1.861	1.782	2.103	2.098						
D	2.403	2.402										
E	2.891	2.789										
F	2.931	3.102										
G												
H												

Figure 6. Plate Reader Values for the Standards, Samples, and Controls in the 96-Well Plate Illustrated in Figure 5

Answers to Scenario Example 1

	1	2	**Average of values in columns 1 and 2. These values are used to construct the standard curve.**	3	4	**Average of values in columns 3 and 4**	5	6	**Average of values in columns 5 and 6**
A	0.004	0.001	**0.003**	0.239	0.242	**0.241**	0.550	0.546	**0.548**
B	0.161	0.153	**0.157**	0.481	0.479	**0.480**	1.344	1.400	**1.372**
C	0.310	0.311	**0.311**	0.801	0.799	**0.800**	0.037	0.028	**0.325**
D	0.623	0.626	**0.625**						
E	0.785	0.783	**0.784**						
F	1.569	1.566	**1.568**						

Figure 7. Averaged Values for the Replicates Using the Plate Reader Measurements Shown in Figure 4

The averages of columns 1 and 2 are used to construct the standard curve shown in Figure 8 below. The averages of columns 3 and 4 are the controls used to evaluate whether the assay was working properly. The averages of columns 5 and 6 are the patient samples.

Figure 8 shows the standard curve for this scenario: the points all lie close to a best fit line. The line is straight and does not plateau. The line runs through zero. So, the points appear to form a reasonable standard curve.

It is possible to determine the concentration of PTH in the controls and the patient samples in two ways:

1. The concentrations can be read off the graph, as illustrated in Figure 8. A line is drawn from the sample's average plate reader value on the Y axis to the best fit line. For the first **+** control, that averaged value is 0.480 AU. Then another line is drawn from the intersection with the best fit line to the X axis, as shown. The result is 62 ρg/mL. For the 100 ρg/mL control, a similar procedure yields a value of 102 ρg/mL.

2. Alternatively, the equation for the trend line on the graph can be calculated or read from Excel and the values for Y can be plugged into the equation. We can then solve for X, which is the concentration of PTH. It is sometimes difficult to read values precisely off a graph, so the algebraic method may be more accurate.

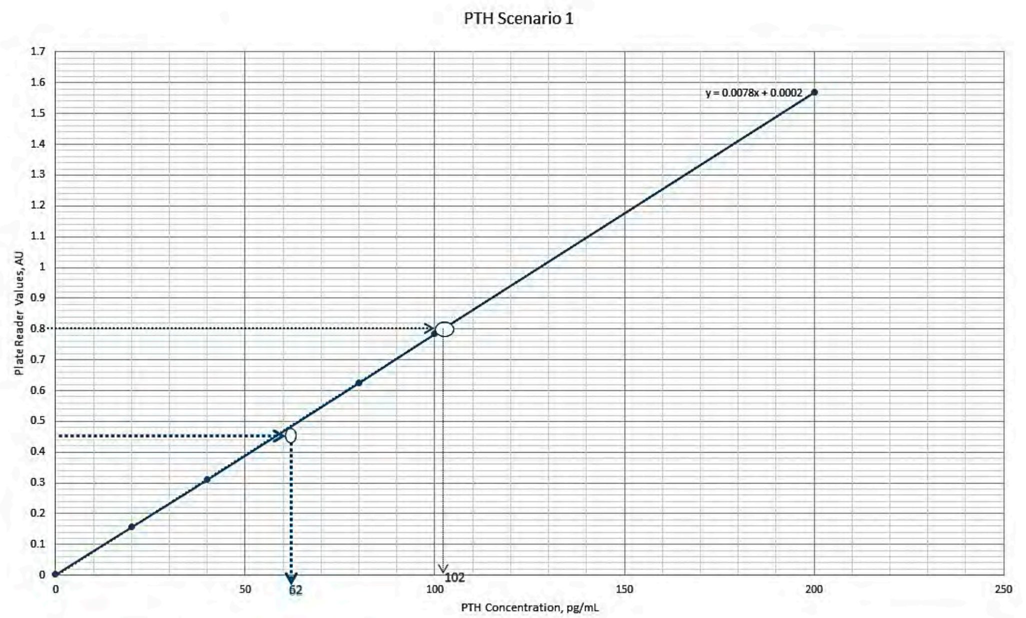


Figure 8. Results from Scenario Example 1

Excel was used to graph the best fit line for the standard curve data. (Before graphing, the values of each of the two replicates were averaged.) The best fit line was then used to find the values for the positive controls.

Algebraic Method:

The equation for the best fit line from Excel is Y = 0.0078X + 0.0002

Plugging in the average plate reader value for the 30 ρg/mL **+** control, that is 0.241 AU, yields:

0.241 = 0.0078X + 0.0002

X=30.87 ρg/mL

Plugging in the average plate reader value for the 60 ρg/mL **+** control, that is 0.480 AU, yields:

0.480 = 0.0078X + 0.0002

X = 61.51 ρg/mL

Plugging in the average plate reader value for the 100 ρg/mL **+** control, that is 0.800 AU, yields:

0.800 = 0.0078X + 0.0002

X = 102.53 ρg/mL

Analysis of controls: The values for the positive controls were calculated using both a graphical and algebraic method. The results of the two methods are consistent. All three **+** controls are within the specified range required. Therefore, it is possible to continue with analysis of the patient samples.

The replicates are averaged as shown in Figure 7, and the PTH concentration is calculated, in this case using the algebraic method:

Patient 1: *0.548 = 0.0078X + 0.0002*

X = 70.23 ρg/mL

Patient 2: *1.372 = 0.0078X + 0.0002*

X =175.64 ρg/mL

Patient 3: *0.325 = 0.0078X + 0.0002*

X = 41.64 ρg/mL

Based on these results, the PTH level of patient 2 appears to be abnormal. Further medical follow-up would likely be recommended for this patient. The other two patient PTH levels are in the normal range.

Answers to Scenario Example 2

1	2	**Average of values in columns 1 and 2. These values are used to construct the standard curve.**	3	4	**Average of values in columns 3 and 4**	5	6	**Average of values in columns 5 and 6**
0.002	0.004	**0.003**	0.988	0.978	**0.983**	0.601	0.603	**0.602**
0.901	0.906	**0.904**	1.505	1.500	**1.503**	1.450	1.440	**1.445**
1.503	1.499	**1.551**	1.861	1.782	**1.822**	2.103	2.098	**2.101**
2.403	2.402	**2.403**						
2.891	2.789	**2.840**						
2.931	3.102	**3.017**						

Figure 9. Averaged Values for the Replicates Using the Plate Reader Measurements Shown in Figure 4

The averages of columns 1 and 2 are used to construct the standard curve shown in Figure 9. The averages of columns 3 and 4 are the controls used to evaluate whether the assay was working properly. The averages of columns 5 and 6 are the patient samples.

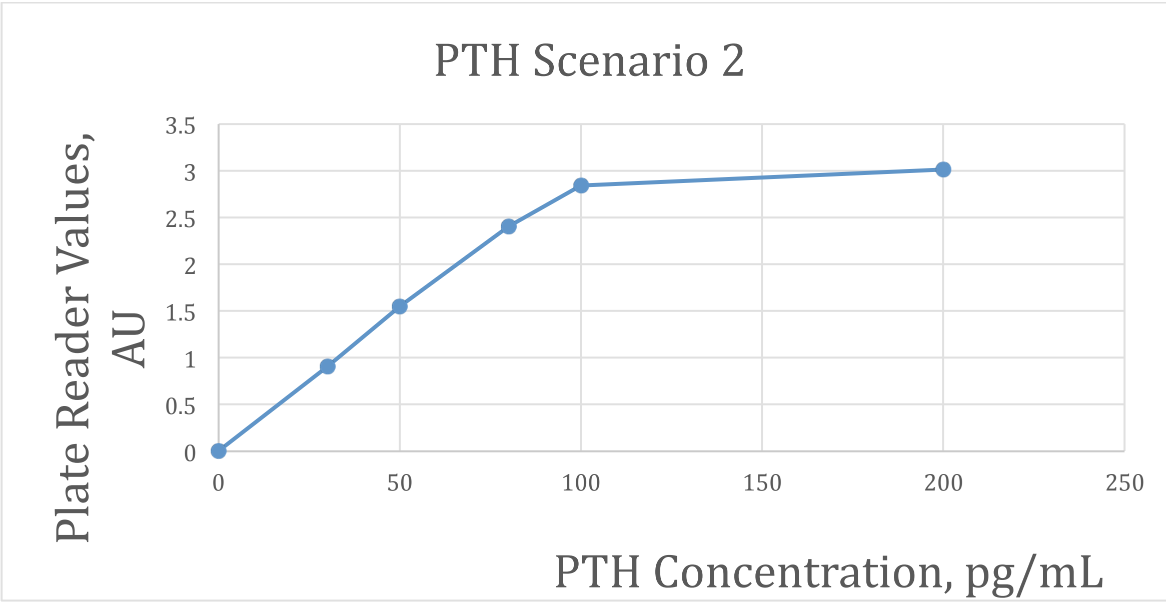


Figure 10. Results from Scenario Example 2

EXCEL was used to graph the best fit line for the standard curve data. (Before graphing, the values of each of the two replicates were averaged.) Observe that the graph plateaus at higher concentrations.

The standard curve plateaus at higher PTH concentrations.* There are various reasons why this might occur, but, whatever the reason, the results of this assay are not valid. Observe that the second **+** control, 100 ρg/mL, should have yielded a reading twice that of the 50 ρg/mL **+** control. It does not, for reasons that are unclear. We know that if the standard curve and the controls do not provide the right results, then the assay is invalid. Do not bother to evaluate the patient samples. In a workplace, the analyst might consult with a supervisor.

---

* There are situations where assays are known to be inaccurate at higher and/or lower levels of analyzed material. In these cases, the reporting range of the standard curve might be reduced to exclude the areas of inaccuracy. The positive controls would be used to establish the accurate, reporting range. In such cases, patient samples that yield values outside the reporting range would need to be retested or tested using another method.

Information and Communication Technology Workplace Scenario

Tech Park Managed Wireless LAN Infrastructure

PART 1 - General

A. The Tech Park Group is seeking proposals for the development and installation of a centrally managed wireless local area network (LAN) system to support office computers, guest computers, laboratory equipment, and wireless mobile devices.
B. Blueprints with building specifications will be provided.
C. Proposals are due no later than 5 days from opening this RFP.
D. No proposals will be accepted after the due date and time specified. No changes will be allowed to any proposal without penalty.
E. Questions may be directed to the Tech Park manager.

PART 2 - Summary of Work

Design, install, set up, and test a fully functioning managed wireless LAN to the owner's specifications:

A. A site survey that includes locations, signal strength, and RF channels for dual band access points (APs)
B. Wireless access points to support data connectivity for 100% coverage within the building and limited or no connectivity outside the building
C. Provision and installation of all equipment for a complete and operational system per project drawings and specifications
D. Network equipment that follows the requirements of the specifications and drawings and all current revisions of the 802.11n standard
E. A platform that will assist in the management, configuration, and maintenance of the wireless LAN
F. A system that supports roaming between APs. It is critical that roaming not complicate deployment or troubleshooting, compromise security, or necessitate multiple client logins and authentications
G. A system that supports WPA2-Personal and AES
H. A system that works with all client types

PART 3 - Site Survey

A. Plot the location of each AP to cover the room with the least number of devices.
B. All access points shall be properly labeled (AP-1, AP-2, AP-3, etc.).
C. All stations inside the building MUST have a RSSI of 0dBm through -50dBm (Fair rating).
D. All rooms need to accommodate no more than 30 users, except the auditorium, which must accommodate at least 60 users.
E. Using the formulas provided, determine the total gain required to cover the area.
F. Set the channel of each AP so it does not interfere with another AP.

G. Provide a document showing:
   1. The location of each AP
   2. Total transmitter gain
   3. Signal strength at each radius
   4. Transmitter channel

PART 4 - Setup, Identification, and Administration

Using your site survey document, locate and set up each access point with the following:

A. Location
   1. Choose the appropriate type of AP
   2. Choose the appropriate type of antenna
   3. Place in the room

B. Setup
   1. AP location/name (as appropriate)
   2. AP external (Internet) IP network:197.30.56.32 255.255.255.224 (APs get the first available addresses)
   3. AP external (Internet) default gateway address: 197.30.56.62
   4. AP external (Internet) DNS address: 151.164.1.7
   5. AP internal (private NAT) IP address: 192.168.15.1 255.255.255.0 (internal default gateway)
   6. All 100 devices to connect starting at IP: 192.168.15.25
   7. Enable DHCP

C. Wireless
   1. Allow N devices only (both 2.4 and 5 GHZ bands)
   2. AP channel (as appropriate) using standard 20 MHz channel width only
   3. SSID: ATEP
   4. Disable SSID broadcasting
   5. Standard WAP2-Personal AES passphrase/key: ATEP-Acce$$
   6. Enable AP Isolation

D. Security
   1. Enable stateful inspection (**dynamic packet filtering)**
   2. Allow FTP and TCP port 80 to be forwarded in and out of the router

E. Administration:
   1. Change the router password to ATEP123
   2. Allow only HTTPS to access the router via wireless
   3. Do not allow remote management

F. Confirm connectivity

PART 5 - Testing

A. All equipment shall be tested for proper operation and be fully functional on completion.
B. When setup is complete, press the Test configuration button.
C. Fix any problems found

PART 6 - Wireless Location Mapping

A. Use the building blueprint and the different radius maps to find the locations of the access points.
B. Each AP can accommodate 30 users.
C. Using the RF Math Formula document, find the RSSI at each radius taking into account any possible interference:
   - All outside walls are made of reinforced concrete with a brick face (25 dBm).
   - Inside walls around the Science Lab are made of reinforced concrete (22 dBm).
   - Other interior walls are made of wood and drywall (5 dBm).
   - Inside line-of-sight access with limited obstructions (2 dBm).
D. You will need to adjust both the 2.4 GHz and 5 GHz.
E. Using the power loss (RSSI) formula, find the signal strength at each radius:
   - Set the transmitter power
   - Set the transmitter gain
   - Set the wavelength
   - Set the interference (n)

   Note: The receiver gain and the receiver sensitivity are set and cannot be changed.

   Note: Receive levels (RSSI) must be less than -50dBm to meet specifications.
F. Set the channels so they do not interfere with other APs.
G. Complete the following chart for each access point:
   - APs location
   - APs total transmitter power
   - APs transmitter channel
   - RSSI inside the room (line-of-sight)
   - RSSI inside the building (outside room through interior wall)
   - RSSI outside building (outside exterior walls)

Access Point Chart

AP Number___________________________________Location:____________________________________

APs IP Address: ____

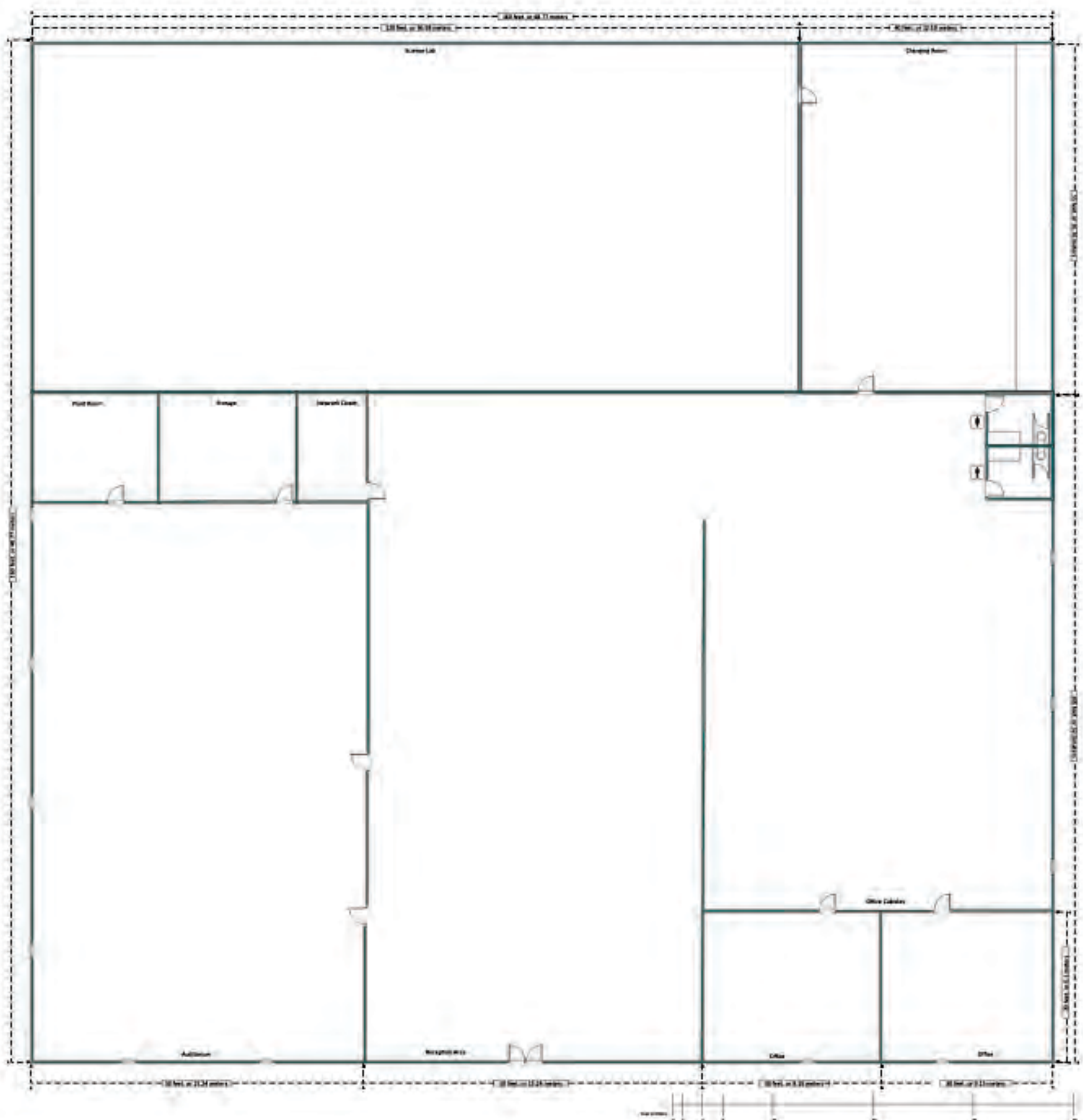
2.4GHz Total Transmitter Power: ________________ Channel: _____________________________________

Inside Room	**Outside Room**	**Outside Building**
1m	1m	1m
3m	3m	3m
5m	5m	5m
10m	10m	10m
20m	20m	20m
30m	30m	30m
40m	40m	40m

5 GHz Total Transmitter Power: __________________Channel:______________________________________

Inside Room	**Outside Room**	**Outside Building**
1m	1m	1m
3m	3m	3m
5m	5m	5m
10m	10m	10m
20m	20m	20m
30m	30m	30m
40m	40m	40m

Floor Layout



Reference Materials

$$RSSI(P_R) = P_T + G_T + G_R - (20log_{10}\left(\frac{\lambda}{4\pi)}\right) - 10n(10log_{10}d)))$$

Constant of 3

$$\lambda = c/(f * 1000000000)$$

Frequency	Wavelength
2.4 GHz	0.125
5 GHz	0.06

Path Loss (dB) *n*

Material	Loss
Free Space or Cubical	2dB
Drywall	4dB
Window or Glass Door	3dB
Metal Door	8dB
Brick, Concrete or Block	15dB
Reinforced Concrete	22dB

Formula Key	
P_T	Power at the Transmitter (dBm) (Intentional Radiator)
P_R	Power at the Receiver (dBm)
G_T	Antenna Gain of the Transmitter (dBi)
G_R	Antenna Gain of the Receiver (dBi)
c	The Speed of Light (299,792,458 meters per second)
f	Frequency of RF (2.4GHz or 5 GHz)
λ	Wavelength (speed of light/frequency)
d	Distance (Meters)
π	Pie – Ratio of a Circle's Circumference to its Diameter (approximately 3.14)
r	Radius (Meters)

Signal Strength	RSSI	Bandwidth
Excellent 100%	0 thru -15	54 Mb
Good 75%	-16 thru -30	54 Mb
Fair 50%	-31 thur -50	48 Mb
Poor 25%	-51 thur -70	24 Mb
Minimal 10%	-71 thur -89	11 Mb
Over Limit	Over -89	0 Mb

Math Formulas

Link Loss Budget (RSSI)

Transmitter Gain (dBm)

#N/A

Maximum of 36dBm or 4watts

Total Power (EIRP)

#N/A

Antenna Gain (dBm)

#N/A

Receiver Gain (dBi) Constant

3

Wavelength (M)

#N/A

Distance (M)

10

n Obstructions

Receiver Sensitivity

-89

Receiver Power (dBm)	
#N/A	1m
#N/A	3m
#N/A	5m
#N/A	10m
#N/A	20m
#N/A	30m
#N/A	40m
#N/A	50m
#N/A	60m
#N/A	70m
#N/A	80m

SNR (0 - 120dB)

Path Loss (dB)

#N/A

Link Margin (dB)

#N/A

Power Loss Formulas

$$P_R = P_T + G_T + G_R + L$$

Typical Throughput Rates

Signal Strength*	RSSI*	Throughput*
Excellent 100%	0 – -15	54 Mbps
Good 90%	-16 – -30	54 Mbps
Fair 50%	-31 – -50	24 Mbps
Poor 25%	-51 – -70	11 Mbps
Minimal 10%	-71 – -89	5 Mbps
Over Limit	>-89	Signal Lost

*Estimates Only

$$SNR = 20 \log_{10} (2^n)$$

$$L = 20 \log \left(\frac{\lambda}{4\pi}\right) - (10n (\log_{10} d))$$

$$P_T + G_T - Receiver\ Sensativity - PathLoss$$

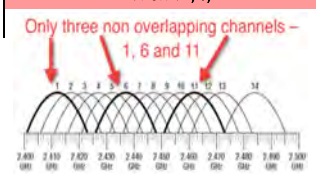
Radio Frequency Obstructions

Type of Barrier	Interference Potential
Open Space	None (0-2dB*)
Wood (Walls, Doors)	Low (4dB*)
Dry Wall	Low (4dB*)
Office Partition	Low (3dB*)
Glass	Low (3dB*)
Cinder Block	Medium (10dB*)
Bricks	Medium (12dB*)
Marble	Medium (12dB*)
Concrete	High (15dB*)
Ceramic Tile	High (13dB*)
Metal	Very high (18dB*)
Mirrors	Very high (20dB*)
Elevators	Very high (22dB*)
Reinforced Concrete	Very high (22dB*)

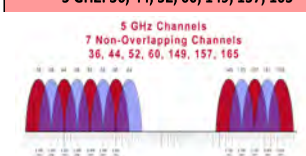
* Approximate values

Channels

2.4 GHz: 1, 6, 11



5 GHZ: 36, 44, 52, 60, 149, 157, 165



Formula Key

P_T	Power at the Transmitter (dBm) (Intentional Radiator)
P_R	Power at the Receiver (dBm)
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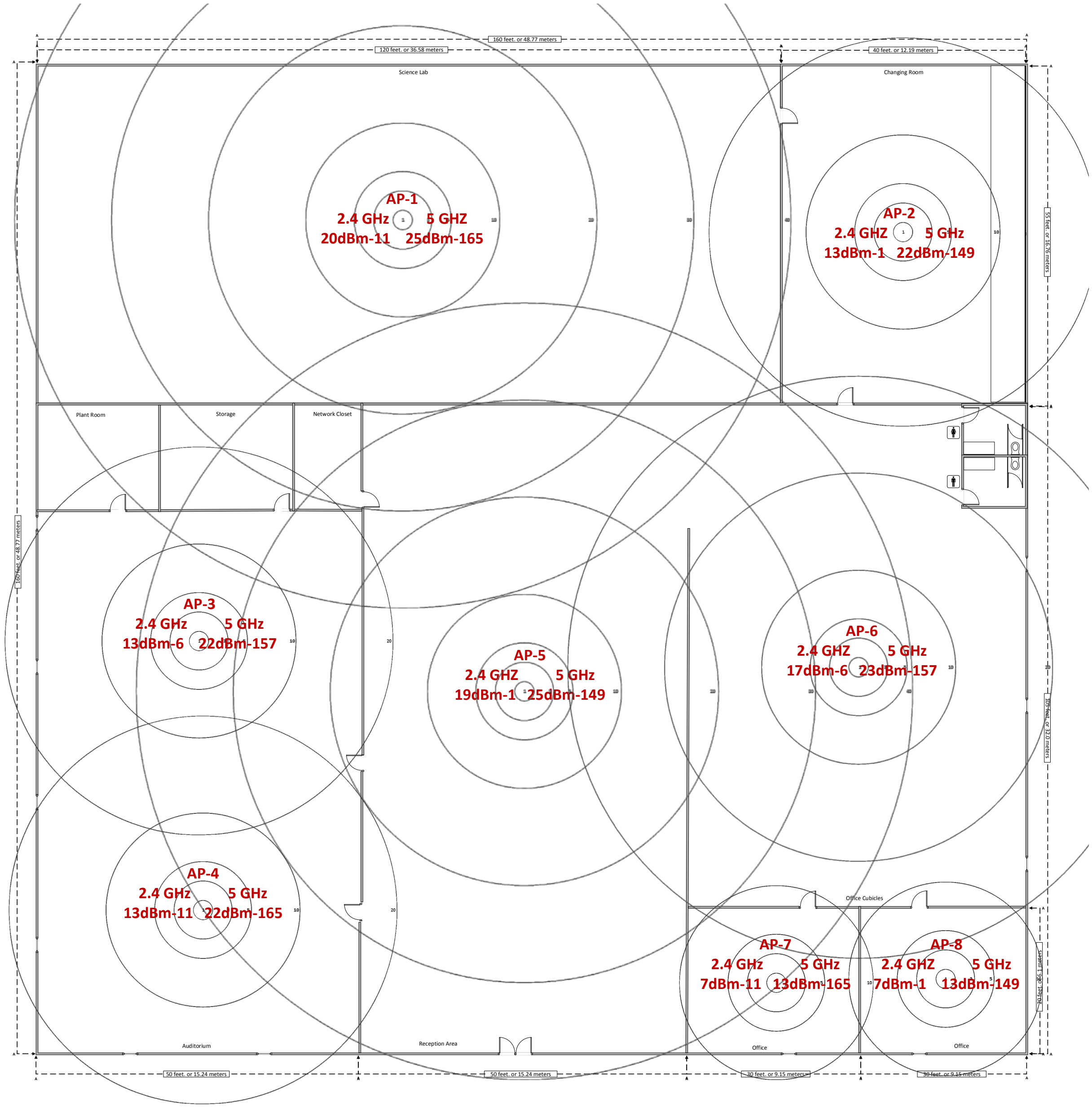
G_R	Antenna Gain of the Receiver (dBi)
c	The Speed of Light (299,792,458 meters per second)
f	Frequency of RF (2.4GHz or 5 GHz)
λ	Wavelength (speed of light/frequency)
d	Distance (Meters)
π	Pi – Ratio of a Circle's Circumference to its Diameter (approximately 3.14)
r	Radius (Meters)
A	Area of Coverage (Meters)
n	Indicates the degree of loss as normally encountered in that environment
L	Path loss between two isotropic antennas in free space (dB)

Access Point Locations



Manufacturing Technology Workplace Scenario

Bid for an MPH Manufacturing Order

CBI is a leading full-service cut-to-size metal service company providing rectangular blocks for use in machining aluminum parts. CBI orders 4 feet by 12 feet rectangular aluminum plates 2 inches thick from a mill and cuts them into rectangular blocks according to customer specifications, to be subsequently milled into products for the aerospace industry. Your job as a technical sales representative is to develop bids for orders from companies like Boeing.

The Task

Develop a bid for an order to produce the blocks requested by MPH Manufacturing with the following finished dimensions:*

4 blocks	10¼" x 46½"
6 blocks	6" x 13"
16 blocks	11⅛" x 17"
3 blocks	3.7" x 14½"

- The plate costs $2.60 per pound. The density of aluminum is 3 gm/(cm^3).
- In order to reduce the machine and labor time turning a saw blade, each cut must go straight across the remaining plate.
- Each cut removes ¼" from the plate.
- Scrap pieces measuring 4 sq. ft. or more can be put into reserve; the customer must pay a restocking fee of $0.70 per pound.
- If the scrap pieces are less than 4 sq. ft., the material goes into the scrap bin, and the customer is charged for the waste.
- CBI charges 22% of all costs except the restocking fee to cover labor expenses, overhead, and profit.

Prepare a bid that gives CBI the best chance to obtain the order over other bids. The bid should be documented with the cost calculations and a diagram of the layout of the blocks on the plate.

* These figures are slightly revised by omitting a few pieces from the actual order.

APPENDIX F
Secondary School Implications

A Conference subgroup of secondary school STEM educators suggested that Career and Technical Education (CTE)/STEM pathways should be designed to maximize student engagement using "real-world/industry" mathematics. Such coursework should satisfy core graduation requirements. STEM and math instructors should work as a team to reproduce the workplace environment with scenarios and context-based assessments.

Gap Analysis

- Provide a complete inventory and alignment of math courses to all STEM courses/pathways by functions (*e.g.,* addition, division, extrapolating, graphing, best fit line, linear regression, finding unknown values, order of operations, interpolating).
- Create a marketing document for initial engagement that targets policymakers and other specific groups.
- Share the math misalignment with administrators, non-math people, and policymakers highlighting what is taught vs. what is needed in the workplace.
- Begin the gap analysis at the middle school level to ensure alignment with workplace needs.

Curriculum Redesign

- Have math teachers, STEM instructors, and industry personnel collaborate to create scenarios based on authentic industry problems/tasks; then use them in curriculum development and PD incorporating the gap analysis at regional or national centers.
- Create a bank of scenarios aligned with STEM courses, fields, and standards, with online access and editable features. Provide detailed answer keys that also highlight common misconceptions and possible errors. This is vital in order for teachers to have confidence in putting new materials into their courses. Videos of teacher explanations of thought processes and problem solving on a whiteboard would be more helpful than text-based materials.

Paradigm Shift

- Require math lab for a certain percentage of class time.
- Allow the STEM and math teachers to be the same person double certified
- Have STEM and math teachers collaborate on campus and meet with industrialists regularly.
- Update curriculum periodically to reflect changes in the workplace.

Policy Changes

- Require state-level training to teach STEM math courses (and include a teacher externship with scenario-based training).
- Allow more flexibility for alternative math courses, as well as math-rich STEM courses, to count for math credit toward graduation requirements.
- Create math classes that are specific to a pathway and team taught by a math teacher and subject-matter expert.
- Require every CTE and math course to have objectives (Students should be able to...). These objectives should include scenario-based learning in both courses.

Teacher Professional Development

- Require working with an advisory board that includes industry representatives.
- Partner with national centers to integrate the scenarios and the contextualized math into existing teacher PD/training.
- Include scaffolding: Use whiteboard samples to show how to explain the concept to students (like Khan Academy videos but focused on scenario-based math).
- Form a cohort from the same school consisting of STEM and CTE teachers with disciplinary and mathematics expertise to collaborate with industry personnel to provide PD. As in-person PD may not be possible for everyone, offer online instruction as well.
- Provide model programs and best practice examples.
- Develop and provide rubrics so that programs can "self-grade," and use them to assess student progress and provide formative feedback.
- Provide a roadmap for implementation at the school and district levels.
- Provide teachers with industry-based experiences.

Sustainability

- Establish regional or national ATE/CTE centers focused on contextualized mathematics that is aligned with the workplace needs.
- Establish a Master Teacher program: STEM and math teachers would work together in collaboration with an industrialist and/or a CC technical program that has an operational advisory board.
- Create and support an online community to share best practices.
- Adopt scenario-based teaching and learning as standard expectations in course knowledge and skills (policy).

NEEDED MATH EXAMPLES FROM EMPLOYERS

BIOTECHNOLOGY

From ADAM JOCHEM, Metabolism Lab at the Morgridge Institute for Research

EXAMPLE 1 BIOTECH

Specify the technical problem to solve:

We culture yeast in several different media. Most commonly, we use YEPD (1% yeast extract, 2% peptone, 2% dextrose). Media must be sterile and the autoclave is most often employed to this end. Unfortunately, dextrose cannot be autoclaved, as it caramelizes at high temperatures. It must be filter sterilized. Filter sterilizing several liters of YEPD is not cost effective. Additionally, it is best to have media sterilized in the flask. Given the above recipe and the information regarding sterilization, how does one make a liter of YEPD?

What would employees be doing on the job that requires math knowledge to address this problem?

Employees use their skills in generating "percent solutions." the formula $C_1V_1 = C_2V_2$, and basic arithmetic to successfully produce YEPD.

Solution: Make a 20% (w/v) solution of dextrose and filter sterilize. Mix 10 g yeast extract and 20 g peptone bring to volume to 900 mL with milliQ water. Autoclave in a 4L flask. After autoclaving, add 100 mL 20% dextrose.

EXAMPLE 2 BIOTECH

Specify the technical problem to solve:

Our laboratory is interested in employing a pyruvate uptake assay which was recently published in a scientific journal. Though the methods section is not very detailed, it appears that the final volume of the uptake reaction is 150 µL. The final concentration of pyruvate is 100 µM and of this, 10% is ^{14}C labeled. The freezer contains a purchased stock of ^{14}C-pyruvate at 55mCi/mmol and 0.1mCi/ml. What volume of ^{14}C-pyruvate is needed per reaction?

What would employees be doing on the job that requires math knowledge to address this problem?

Employees use their knowledge of metric system and their familiarity with orders of magnitude. Since the molar concentration of the ^{14}C-pyruvate is not obvious, technicians use their multiplication and division skills to arrive at this answer. In addition, employees must factor in percent and take into account a target volume.

Solution: Cross multiply and divide to obtain the molar concentration of ^{14}C labeled-pyruvate (1.8 mM). Then convert mM to µM (1800 µM) Next multiply desired final concentration of total pyruvate (100 µM) by 0.1 to determine the concentration of labeled pyruvate needed (10 µM). Then use $C_1V_1 = C_2V_2$ to determine volume of labeled pyruvate needed in a 150 µl reactions (0.83 µL).

EXAMPLE 3 BIOTECH *Specify the technical problem to solve:*

The drop assay provides a semi-quantitative assessment of yeast growth. It is useful in comparing strains of yeast or assessing the effect of growth inhibitors. Yeast cells cultured in liquid media are pelleted, re-suspended to a known concentration in drop assay medium, serially diluted, and finally dropped onto nutrient/agar plates. The "drops" each contain a different number of yeast cells- 10^4, 10^3, 10^2, 10 each in a volume of 4 µL. Employees must map out a path to get from yeast growing in liquid culture to the completed drop assay plates, armed with the knowledge that 1 OD_{600} unit is equal to 1 x 10^7 yeast cells per mL.

What would employees be doing on the job that requires math knowledge to address this problem?

Employees use their familiarity with numbers expressed as exponents. This is another instance in which knowledge of metric units of volume is critical. Basic arithmetic is employed with numbers expressed as exponents.

Solution: Using the OD_{600} measurement, determine the volume of culture that contains 2.5 x 10^5 cells. The cells are then pelleted and re-suspended in 100 µL of assay medium, resulting in 2.5 x 10^3 cells/µL. The cells suspension is placed in a microtiter plate and 1:10 serial dilutions are made (10 µL of cells + 90 µL of medium). Finally, 4 µL of each dilution is dropped onto nutrient/agar plates.

From SULATHA DWARAKANATH, Nano Science Diagnostics Inc.

EXAMPLE 4 BIOTECH
Specify the technical problem to solve:

Making dilutions and recording all the calculations.

What would employees be doing on the job that requires math knowledge to address this problem?

Technicians will be making dilutions and calculating concentrations for various experiments.
Example: using C1V1 = C2V2 and solving for V1; the mathematics relates to ratios and proportions, solving the C1V1 = C2V2 equation, understanding linear relationships, and being able to construct a linear plot and use it to get information.

From KEVIN SIMPSON, Autoimmune Technologies LLC

EXAMPLE 5 BIOTECH
Specify the technical problem to solve:

Determine how much media to add to cells to achieve a particular cell density in a flask of a given size.

What would employees be doing on the job that requires math knowledge to address this problem?
The employee would need to calculate the concentration of cells by applying the equation relating to haemocytometer counts and then determine how much media to add to the cells to attain the correct cell density.

EXAMPLE 6 BIOTECH
Specify the technical problem to solve:

Build an experimental ELISA protocol and scheme.

What would employees be doing on the job that requires math knowledge to address this problem?

Often in our workplace technicians are asked to run ELISA assays. And while there is a general protocol for ELISAs available, many times the techs are given non-detailed instructions. It is left up to the bench scientist to figure out what volumes (and sometimes what dilution schemes) to use in the prep of the samples and controls. The employees need to know how to calculate concentrations, volumes necessary and dilution schemes for controls and samples. They need to be able to prepare a workable ELISA scheme before they start based on generalized instructions.

EXAMPLE 7 BIOTECH
Specify the technical problem to solve:

Prepare a variety of solutions at different concentrations and be able to use what is on hand.

What would employees be doing on the job that requires math knowledge to address this problem?

When preparing solutions in the lab, the technicians need to be able to translate a target volume and concentration into an actionable problem to solve. If we are making up "Running Buffer" for our Äkta purification system, it calls for a 20 mM sodium phosphate solution (among other components). But, if the lab is out of the heptahydrate (+7 H_2O) version of the chemical, the technician would need to know how to re-calculate the amount of sodium phosphate to use with a different version of the chemical (say anhydrous, no extra waters). They would need to be able to work a concentration equation (based on molecular weight) to determine the amount needed for a target concentration.

EXAMPLE 8 BIOTECH
Specify the technical problem to solve:

Preparing protein samples for gel electrophoresis.

What would employees be doing on the job that requires math knowledge to address this problem?

Our lab runs gel electrophoresis for a variety of project goals. Part of the process is determining how much protein solution to add to the well of the gel in order to have a specific protein amount in a band (for visualization later). The technicians need to know how to determine how much protein solution to add to a well based off of the individual protein concentrations (and the target protein range for the gel). If they are running a 12-well gel with 10 unknowns, they would have to determine (based on the concentrations of the individual solutions) how much of each protein solution to pipette into the loading buffer (up to 10 times for this example).

From DEBRA THOMPSON, Asuragen

EXAMPLE 9 BIOTECH

Specify the technical problem to solve:
Review fill volume check data to measure the fill process capability (Cp & Cpk)

What would employees be doing on the job that requires math knowledge to address this problem?

Collate manual volume check data (recorded in µL) across multiple lots. Calculate the average fill volume and standard deviation then, using the upper and lower specification limits calculate the CP (process capability) and CPK (Process Capability Index).

$$C_p = \frac{\text{USL} - \text{LSL}}{6 \times \text{ std. Dev}} \quad C_{pk} = \min\left(\frac{\text{USL} - \text{mean}}{3 \times \text{ std. Dev}} \cdot \frac{\text{mean} - \text{LSL}}{3 \times \text{ std. Dev}}\right)$$

Note: We use statistical tools like JMP or MiniTab to do this analysis over these large data sets. However, understanding the formulas used to derive these values and what they mean is very valuable.

EXAMPLE 10 BIOTECH
Specify the technical problem to solve:

Continually track the results of functional testing to provide an early warning of production issues.

What would employees be doing on the job that requires math knowledge to address this problem?

Develop a control chart which includes calculating the average, the upper control limit and the lower control limit.

EXAMPLE 11 BIOTECH
Specify the technical problem to solve:

1. Concentration (cp/µL) = $10^{\text{(FAM Ct-internet / slope)}}$
   Where FAM Ct = 28.4
   Intercept = 36.8
   Slope = –3.6
   Conc (cp/µL) = 221.98

1. % Efficiency = (10(–1 slope) –1) x 100

Where slope = –3.6
% Efficiency = 89.6%

What would employees be doing on the job that requires math knowledge to address this problem?

Manufacturing batch calculations, quality control testing, batch formulation.

From JO-ANNE HONGO, JS Hongo Consulting

EXAMPLE 12 BIOTECH
Specify the technical problem to solve:

Determine if buffers and/or cell culture media were prepared correctly.

What would employees be doing on the job that requires math knowledge to address this problem?

Employees prepare buffers and cell culture media as a core service, supporting the work of other groups/laboratories in the company.

EXAMPLE 13 BIOTECH
Specify the technical problem to solve:

Determine if standard curve and/or control dilutions were prepared correctly.

What would employees be doing on the job that requires math knowledge to address this problem?

Employees routinely perform assays (e.g. ELISA) to determine (1) the production level of a recombinant protein (therapeutic) during the manufacturing process and (2) the level of proteins in pre-clinical and/or clinical patient samples.

EXAMPLE 14 BIOTECH
Specify the technical problem to solve:

Determine if buffers and/or reagents were prepared correctly.

What would employees be doing on the job that requires math knowledge to address this problem?

Employees routinely perform assays (biochemical and cell-based) to identify potentially therapeutic monoclonal antibodies.

INFORMATION AND COMMUNICATION TECHNOLOGY

From CATHY BALAS, Balas Consulting Services

EXAMPLE 1 ICT
Specify the technical problem to solve:

The employer has purchased a new server. The server size was determined by senior level IT systems engineers. The IT department has asked an IT employee (assume a two-year associate degree) to parse the data storage space among the entire workforce. Senior level staff are to receive more storage space than other staff. IT staff are to receive more storage space due to their position duties. The IT employee is assigned the responsibility of surveying every staff member and determining what amount of server space is appropriate for each category of the workforce. The employee is then tasked with writing code to parse the server space according the demand.

What would employees be doing on the job that requires math knowledge to address this problem?

This task would require discrete math and college algebra skills to determine the server space allocations, and the ability to code.

EXAMPLE 2 ICT
Specify the technical problem to solve:

The employer has implemented the solution to Problem 1 and while it is a good solution overall, there are times when certain segments of the workforce are extremely busy and have run out of server space. During these times, other segments of the workforce were not even using their allotted space or if so, they were using the bare minimum amount of space. The employer has asked the IT employee to take into consideration the time factor and redistribute server space according to the demand.

What would employees be doing on the job that requires math knowledge to address this problem?

The IT employee would need to use math to analyze the usage data to determine peak usage from the workforce users and the ability to code dynamic (changing) user loads in order to redistribute server space according to the demand.

Subnetting could be a part of this solution. From a mathematical perspective, each IPv4 address is made up of four - eight bit binary octets for a total of 32 bits. For each bit, the binary is raised to the power of two. Subnetting allows you to borrow bits from the network portion of the address and subnet them to the hosts. For example:

Class A-**255**.255.255.255 with the first octet as the network portion and the last 3 as the host portion.

Class B-**255.255**.255.255 with the first and second octet reserved for the network portion and the third and fourth reserved for the host portion.

Class C-**255.255.255**.255 with the first, second and third octet reserved for the network and the fourth reserved for the hosts.

EXAMPLE 3 ICT

Specify the technical problem to solve:

With the increased use of automation for electronic systems that are found in cooling systems for servers, more technical data is required to determine troubleshooting solutions. This data is collected using sensors, which is then feed data back into the system to make adjustments. The data can also be used to predict part life analysis and when future maintenance will be needed. The employee is asked to analyze this information to schedule maintenance and change out parts.

What would employees be doing on the job that requires math knowledge to address this problem?

This task involves processing large amounts of data such that it can be used to identify problems and solutions. This requires use of math for current diagnostics and for predictions. Coding and understanding coding is also needed. Graphing and displaying data and then using the info to schedule periodic data is the need. Some or perhaps even all of the graphing can be done by the machine so that the need could be limited to being able to read and understand graphs.

From MARK TAYLOR, CVS Health
(an ICT employer who provided both ICT and MFG examples)

EXAMPLE 4 ICT
Specify the technical problem to solve: Various problems

What would employees be doing on the job that requires math knowledge to address this problem?

An entry level IT/Communications associate should have a solid understanding of the following;

- Basic math skills to understand how much data is stored (or is moving to/from) a location (node). Often these are in Mega, Giga, or Terabytes.
- Concept of time with respect to cycles, for example Megahertz and Gigahertz
- Binary, Decimal and Hexadecimal numbers and conversions
- Binary Logic functions such (Gates AND, OR, NAND, NOR, etc.)
- Concepts of a checksum and encryption
- All of these are needed to understand network addressing, masking, communications and computer processing in general.

Also, wireless networking is commonplace, and the term *bandwidth* is used as a measure of how much data can pass to a node. Large file sizes (gigabytes) need to fit through communication devices that have limits in Megabytes (or MegaBITS) that need to be understood. The path from the source to the endpoint will be limited by the lowest capacity device in the network path. Technicians need to both understand what to expect and set expectations with the user/customer.

From TOM CONNERY, formerly with CA Technologies

What entry-level technicians should know or be able to do:
Project management fundamentals: cost of assets & people. Determine whether a project is forecasting properly based on trending spend versus current or planned revenue. What about unplanned events? Anyone going into manufacturing, technical, or software fields should have some level of project management knowledge and familiarity with the math associated with it. This would likely benefit entry-level technicians as I have seen techs or IT support people sometimes transition to Project Management Institute-certified project managers. PMs can be paid upward of $100K annually and are routinely in demand. As students progress in their careers, it can be a good area to move into long term—provided they have a core technical background.

EXAMPLE 5 ICT
Specify the technical problem to solve:

You are part of a technical or software project and need to determine if your planned work is in line with the proposed schedule.

What would employees be doing on the job that requires math knowledge to address this problem?

The scheduled variance will give you the difference between how much you completed vs. what is still planned; a positive value would mean that you are likely ahead of schedule. This example assumes the individual knows how much per hour it costs for themselves or their team to complete a unit of work.
Scheduled Variance = Earned Value - Planned Value
EV – how much you planned to spend for the work you actually did
PV – how much you planned to spend for the work you planned to do
There are other helpful calculations as well:
AC – how much actually spent for the work actually completed
Cost Variance = EV-AC where a negative value means the project is over budget

EXAMPLE 6 ICT
Specify the technical problem to solve:

You are part of a small team 24 x 7 operation who is manufacturing circuit boards for a trending product line. With the holiday season approaching, your boss has asked you to forecast the total number of units that your team can commit to building in the next 60 days.

What would employees be doing on the job that requires math knowledge to address this problem?

Based on the previous time periods, 30 days, 60 days, 180 days, as well as planned resource time off or other potential for disruption, the worker should understand how to carefully review trending and total output based on workshift and potential disruptions that should allow him or her to obtain an educated estimate as to how many circuit boards they can safely commit to. Each shift may have different output levels that need to be tweaked or enhanced in order to estimate properly and output the best number possible.

MANUFACTURING TECHNOLOGY

From MATTHEW THOMPSON, Toray Composite Materials America

EXAMPLE 1 MANUFACTURING

Specify the technical problem to solve:

Prepare a 1.5% concentration sizing bath (sizing is the chemical treatment applied to the surface of the carbon fiber product) by diluting a 20% resin/80% water mixture.

What would employees be doing on the job that requires math knowledge to address this problem?

Employees would need to calculate how much sizing mixture and water to add to the sizing bath to give a final concentration of 1.5% sizing, say for 50 gal of final sizing bath volume.

Further explanation:

The quantity of the 20/80 mixture is not given, so they would have to figure out how much of both the mix and the water to add to make the final bath 50 gal of 1.5% concentration of sizing.

The 1.5% concentration of sizing in the final bath is the concentration of the resin not the mixture that you were using. So, I would start with the 1.5% concentration requirement: 0.015 = *V*_res/*V*_bath, where *V*_bath = 50 gal, so we need *V*_res = 0.015**V*_bath = 0.015*50 gal = 0.75 gal. To get this, all of the resin is going to come from the mixture that we are adding and the mixture is at a 20% concentration: 0.20 = *V*_res,mix/*V*_mix and again all the resin in the bath is coming from the mix so *V*_res = *V*_res,mix, therefore it becomes 0.20 = *V*_res/*V*_mix, which we can solve for *V*_mix to give us *V*_mix = *V*_res/0.20 = 0.75 gal/0.20 = 3.75 gal.
Now, we have how much of the mix we need to add in the bath, but we still need to figure out how much water. The mix and the water are the only things going in to make up the total 50 gal, so
*V*_bath = 50 gal = *V*_mix + *V*_water, solving for *V*_water will give us
*V*_water = 50 gal – *V*_mix = 50 gal – 3.75 gal = 46.25 gal.

So, the answer is 3.75 gal of the 20/80 mix and 46.25 gal of water.

There are many ways to solve this. It is an algebraic problem, solving a set of equations. I just did this on paper and first had 6 Equations, 6 Unknowns, which I condensed to 4 Equations, 4 Unknowns by eliminating some of the unknowns that don't matter to us in the end. The solution I gave above is solving those 4 Equations, 4 Unknowns. You can also set something like that up in a linear algebra solution method using matrices, which is helpful when there are even more # Equations, # Unknowns.

Alternatively, a technician could also do a sort of guess and check method. Add some mix and some water up to about 40-45 gal using past experience to judge how much of each would be appropriate to get to the 1.5% final concentration. Then measure the concentration using something like the refractive light index test described in the next problem. If the concentration is low, then add a bit more mix compared to water to bring the bath up to about 50 gal, and check again. If the concentration is high, then add more water. If you get to 50 gal and your concentration is still off, drain some and try again. This is obviously wasteful at that point unless the technician has enough "feel" for it from experience.

EXAMPLE 2 MANUFACTURING

Specify the technical problem to solve:

Calculate the sizing concentration in the bath based on refractive light index testing.

What would employees be doing on the job that requires math knowledge to address this problem?

Refractive light index testing can be used to indirectly measure the concentration of solids in an aqueous emulsion. The employee would first need to create a master curve by preparing several samples with known concentrations of sizing and measuring the refractive light index of each of them. This master curve is linear, that is refractive light index decreases linearly with respect to increasing concentration of sizing in the emulsion. More often, the master curve has already been prepared, and the employee must simply use the linear equation to calculate sizing concentration based on the measured refractive light index for his/her sample. If the linear equation is not available, the employee may also be required to linearly interpolate between data points on a graphical master curve.

Further explanation:
Typically, I think the technician would be supplied a $y = mx + b$ linear equation. So someone has already made the master curve to find m and b, and the employee would simply make the measurement and insert as x and solve for y. For new materials, a technician in our research & development area would have to create the master curve themselves first, but it would still end up being a simple $y = mx + b$ linear equation. They would enter the datapoints (x and y) into Excel and find the slope and intercept m and b using a linear fit.

I included the idea of having to interpolate from a graph as a similar extension of this, but I don't think we have to do that for this testing at least. It would be good for an employee to be able to do that though.

EXAMPLE 3 MANUFACTURING
Specify the technical problem to solve:

For Quality Assurance (QA), calculate the interlaminar shear strength (ILSS) of a composite laminate made using the carbon fiber that we produced and a standard epoxy resin by performing the mechanical test called short beam shear testing.

What would employees be doing on the job that requires math knowledge to address this problem?

An employee would be required to prepare the test specimen by first combining the carbon fiber and epoxy resin, then applying the appropriate number of layers of "impregnated" carbon fiber in a mold to make the desired final thickness of the specimen, then curing the laminate in a hot press according to the cure procedure for the resin and the standard procedure developed for the press lamination method. Then, the employee would be required to cut the specimen to the correct dimensions, within the specified tolerance for each dimension, and test the specimen according the standard procedure for the short beam shear mechanical test. Finally, the employee would calculate the ILSS of the composite using the following equation, $ILSS = 0.75*[P/(b*t)]$, where P is the maximum load observed during the test, b is the width of the specimen, and t is the thickness of the specimen.

Further explanation:
In the end the math portion for this is simply plugging numbers into an equation and solving; order of operations is definitely important here. For this example, though, there is also a lot of following procedures given by written “Work Instructions.” In this case, there are 4 Work Instructions to complete it: 1) Impregnate the carbon fiber sample, 2) Press laminate the test specimens, 3) Cut the test specimens to the correct dimensions, and 4) Perform the Short Beam Shear mechanical test.

For (1), the only real math is making sure that the correct sample was taken from production based on our “trace” numbers, which designate exactly where the sample came from in the production, e.g. production line, etc. An engineer makes the sampling schedule which is randomized to as much extent as possible. The technician just needs to make sure not to transcribe any of these trace numbers incorrectly.
For (2), the technician needs to figure out how many layers of the impregnated carbon fiber strands are needed to make the laminate test specimen. That is simply solving *N*_layers = *t*_specimen/*t*_layer, and getting as close as possible to the desired *t*_specimen.

For (3), the technician needs to understand tolerances. The test specimen dimensions are given based on the end thickness of the laminated and cured specimen from (2). So, for (2), the target *t*_specimen was 2.00 mm, but for (3) the dimensions of the cut specimens will be *t* x 2*t* x 6*t* for thickness x width x length. For the tolerance aspect of this, listing the target thickness at 2.00 mm means that the 2 decimal places are significant, and the thickness should fall somewhere on the order of 1.95-2.05 mm. In this case, a range is not explicitly stated, but often it will be, e.g. 2.00 mm ± 0.05 mm. Also, since we are an American company that is a subsidiary of a Japanese company, employees should be able to convert units between standard American and metric. So, that tolerance would be 2.00 mm*(1 in/25.4 mm) = 0.078740 in = 0.0787 in (significant figures) ± 0.05 mm*(1 in/25.4 mm) = 0.0019685 in = 0.0020 in: 0.0787 in ± 0.0020 in. In reality, that is pretty difficult to measure to that precision, and the tolerance would practically be 0.079 in ± 0.002 in.

From MARK TAYLOR, CVS Health
(an ICT employer who provided both ICT and MFG examples)

What entry-level technicians should know or be able to do:
The broader concepts of how manufacturing works are the real challenges. That includes the terminology and the need to understand what problems the company is facing. These are areas that can keep a smart but inexperienced team member from adding value and being recognized.

Here are a couple of examples that frankly show how little we depend on the math skills of our newer team members.

EXAMPLE 4 MANUFACTURING
Specify the technical problem to solve:

Completed assemblies placed into a machine are crashing against each other, damaging parts, and generating software errors. Issue research indicated all parts met their specifications. Everything was properly assembled. Parts were still crashing.

What would employees be doing on the job that requires math knowledge to address this problem?

Physical parts must meet specifications that include a tolerance factor. The tolerance can be larger (+) or smaller (-) by a margin of error. For example +/- .001 (one thousandth of an inch), will be written on the design document. After investigation by a determined technician, it was discovered that when all parts were at the same end of their tolerance; for example all smaller and at the tolerance limit, the combined variation exceeded the full tolerance of the finished assembly. For example: 6 parts that fit together had a combined tolerance of (+/-) .001 inch, creating an out of specification component of (6 x .001 = .006). The final assembly could not be more than .003 inches out of specification – or it would make contact with another moving part. This is a simple issue of the engineer/designer using the default value when specifying the tolerance on the design documentation. Because the parts generally come in with variation in both directions it wasn't discovered for several build cycles. Creating a "Random" nature to the exception that created havoc for a short while.

EXAMPLE 5 MANUFACTURING
Specify the technical problem to solve:

A **s**upervisor asks, "Will we be able to complete the planned number of assemblies in time to ship product at 5 o'clock today?"

What would employees be doing on the job that requires math knowledge to address this problem?

All basic math skills along with the knowledge of how and when to use them are needed. **Calculate** the time it takes to build/assemble product, possibly including packaging for shipment. **Add** current assemblies and/or sub-assemblies for current state. Determine a **percentage** complete for any work-in-progress. Also need to: Determine amounts needed (**addition** and **multiplication**) to complete the work. **Subtract** completed work and defects from the total needed. **Multiply** "time needed per unit" by "quantity to produce" to determine how long to complete (**math with Time**). **Divide** package sizes of raw materials to calculate part requirements e.g. we need 6 boxes of 8 parts per box.

EXAMPLE 6 MANUFACTURING
Specify the technical problem to solve:

Employees are asked to participate in Six Sigma training to reduce defects and improve quality/profitability.

What would employees be doing on the job that requires math knowledge to address this problem?

Teams are introduced to measurement methods, ratios, and formulas that allow comparison between the current and future state – which helps identify progress in their quality initiatives. Required: Basic math skills; addition, multiplication, subtraction, division and work with fractions and decimals is essential. Building basic math operations into formulas and comparing results.

Bonus Challenge (not a math issue at all honestly):
Material Requirements Planning (MRP) is an ongoing balance of logistical processing. The goal is to manage purchasing to meet the needs of the production line – and the best examples are "Just In Time" systems that avoid inventory (i.e. money) tied up on the shelf, or employees standing around waiting for materials so they can go to work.

A good MRP system should provide answers to the general questions: When will products be available and at what cost? Or, what can we build today based on the inventory of parts on hand and expected deliveries? Problems show up when changes occur on either the demand side (customer stops/holds an order), or on the supply side with manufacturing or delivery delays - such as a needed machine is down for maintenance. Management needs to know how the changes will impact productions, and possibly other downstream impacts.

Further Explanation/Conclusion:
Generally, new technicians know little or nothing about the MRP process, and frankly how a manufacturing shop floor works. Setup Time, Requirements, Work In Process, Lead Time, and the concept of Scheduling are new, and the understanding of what they are, and how these concepts impact the workflow are understandably not part of a technical curriculum. But, being able to respond to management questions, and better yet solve problems associated with key parts of the operation, can be critical for success.

Software developers have similar issues – they estimate delivery times based on how long it may take them to type in a list of instructions, but new developers don't consider their own setup and testing time (which may include development of test data, etc.) and other time-consuming work that impacts their delivery.

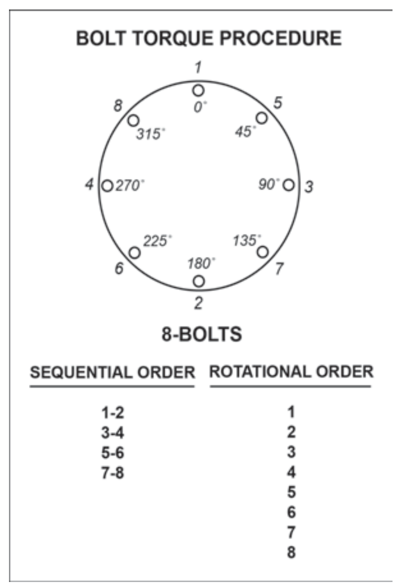
From JANA WALLACE, Process Equipment & Service Company, Inc. (PESCO)

EXAMPLE 7 MANUFACTURING

The drawing above is the patented LPUD 3-Phase Production Unit. When crude oil is produced, it's generally a mixture of oil, water and natural gas. A 3-phase (oil, water and natural gas) production unit is located near the well head. The crude oil flows into the vessel and is separated due to gravity. Water has a greater specific gravity than oil and the gas is the lightest of all three. Therefore, the water settles to the bottom, the oil stays at a higher level, and the gas (a vapor) rises to the top. To speed this process, a fire tube, heating coil, or water bath heater is often used to break up the oil-water emulsion. A dump valve placed low in the vessel will allow the removal of the water, which is usually re-injected back into the ground. The oil will be removed via a dump valve placed higher in the vessel. The oil will be stored on site for future transportation or sent into an oil pipe line. The gas flows through the top of the vessel and is sent into a gas gathering pipeline for further processing and transportation.

Specify the technical problem to solve:
The following problems are typical of what is encountered in this manufacturing business.

1. If a joint of 1" pipe is 21' long and there needs to be 675 – 13.5"-long pieces of pipe cut, how many joints of pipe will it take for all 675 pieces to be cut?
2. A natural gas burner is 70% efficient. The burner is rated at 1,000,000 BTUs per hour, and natural gas will provide 1,000 BTUs per standard cubic feet. How many standard cubic feet of gas will be required for the burner?
3. If the tallest legal shipping height is 13'-6" and a truck bed has a height of 36", what is the tallest load that can be shipped legally on the truck?
4. If the maximum legal shipping weight of a loaded truck is 80,000 pounds and the empty weight of the truck and trailer is 32,000 pounds, what is the maximum weight of the cargo that can be shipped legally?
5. If 75,000 pounds of steel is required for a finished product, and the waste will be approximately 14%, how much weight of steel will need to be furnished?
6. (a) The total surface area of a vessel to be painted is 2000 ft^2 and one gallon of paint covers 160 ft^2 to achieve a dry film thickness of 6-12 mils. To prevent corrosion, an epoxy coating must be mixed with the color coat at a ratio of 80% epoxy to 20% color coat. How many gallons of epoxy and how many gallons of color coat will be required to achieve full coverage of the vessel? (b) If the epoxy costs $95 per gallon and the color coat costs $75 per gallon, how much will the paint cost to paint the entire vessel?
7. If the specifications require 750,000 BTUs of heat transfer per hour from the fire tube in a production unit and the flux rate is 10,000 BTUs per ft^2 per hour, how many feet of 12.75" (outside diameter) pipe is required for the fire tube?
8. All vessels that are welded and designed to withstand high pressures must be hydrotested to make certain all welds are strong and can withstand required pressures. Forty barrels of water must be used for this testing procedure. There are 42 gallons of water per barrel and each gallon of water weighs 8.7 lbs. How much weight will be added to the vessel when this test is performed? Explain why this information is extremely important.
9. Flanges are used to attach sections of a vessel. The ½" bolts must be tightened to produce a specified bolt stress. Given the following Bolt Torque Procedure for 8 half-inch bolts, torque must be applied in 33 1/3% steps of required final torque following the rotational order.



For 7,000 pounds per in^2 (psi) of bolt stress, a total of 84 foot-pounds must be applied using a torque wrench. How many times will an assembly worker have to complete the rotational order? How many foot-pounds of torque must be applied throughout the first rotation?

From NATE MONROE, Toray Composite Materials America

EXAMPLE 8 MANUFACTURING
Specify the technical problem to solve:

Toray's business is focused on manufacturing advanced composite materials for the aerospace industry.

a. The material comes in many different formats from carbon fiber filaments to finished goods such as resin impregnated tapes and fabrics.
b. There is often a challenge with conversions from material length, area, and mass. The prepreg material (a reinforcing fabric which has been pre-impregnated with a resin system) is made to an area density (mass/area) with a given roll width, so if you know the length one could calculate the total area and mass. If you know the area and roll width, one can calculate the length and mass. If you know the mass of the roll with a given width, one can calculate the area and length. Mathematics for dimensional conversions would be helpful to technician success.
c. Math focused on unit conversions from metric to US and US to metric would also be helpful to technician success.

From BILL FRAHM*,* **4M Partners, LLC** (not attending conference)

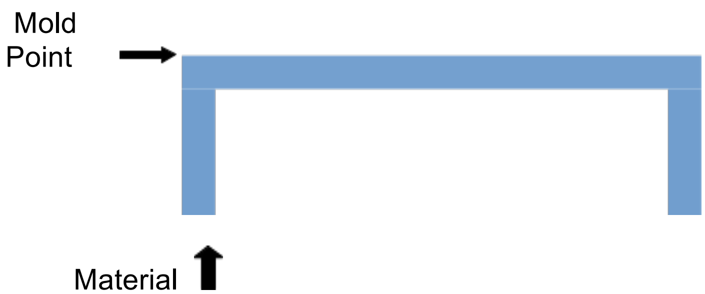
Preface to Manufacturing Example 9. What entry-level technicians should know or be able to do in precision sheet metal forming.

I consider the tool/die maker a technician. They are highly skilled tradesmen who do the shop floor work building the stamping dies and associated tooling needed to form a part. Their math requirements would be what I consider middle school to early high school math. Their skills should include basic math, geometry, trigonometry, and basic algebra. A designer is generally a staff level engineer. Their skills include forming simulation, understanding graphical representations of mechanical properties (tensile strength, forming limits), advanced geometry and trigonometry, and basic calculus. In a nutshell, the designer specifies geometry, component interfaces, and material grades. The tool and die makers shape and build the tools to deform the flat sheet metal blank in the press. Precision sheet metal forming is driven by energy and geometry. For the skilled technician, reliably forming successful components requires the ability to measure angles, curves, and linear surfaces. An understanding of precision measurement of tools and components as well as energy output are also important. Primarily, the tradesman will require "shop math." Shop math requires middle school level mathematics proficiency, as well as an understanding of geometry and trigonometry. This includes such tasks as calculating the radii of bends and curves and determining the surface area of materials in a curve. Designers must also understand how to predict and measure material thinning during a deep draw process, read graphs for tensile properties (plotting engineering stress against engineering strain) and Forming Limit Curves (plotting observations of material failures for strain rates across two axes).

EXAMPLE 9 MANUFACTURING
Specify the technical problem to solve:

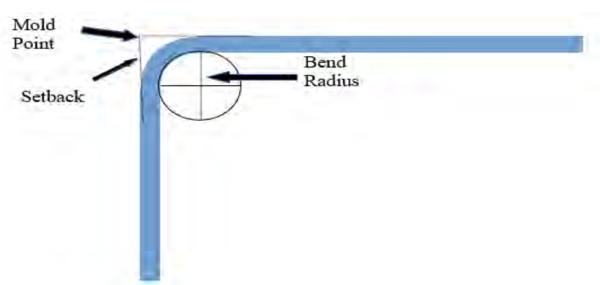
The following example is of a task that would be conducted by a tool or die maker. The problem to be solved is to bend a flat sheet metal blank around a tool. The challenges faced by the die maker are to bend the sheet within the tolerances of the grade and thickness of the metal, meet the geometric specifications of the formed component, and calculate the size of the blank both to meet the requirements to form the component and to eliminate unnecessary scrap.

Further explanation:
Assume we want to form an open box requiring a 90º bend on the ends of a flat piece of sheet metal. The long edge we will call the flat, the two short edges we will call flanges.
In profile, the theoretical finished part looks like this:



What would employees be doing on the job that requires math knowledge to address this problem?

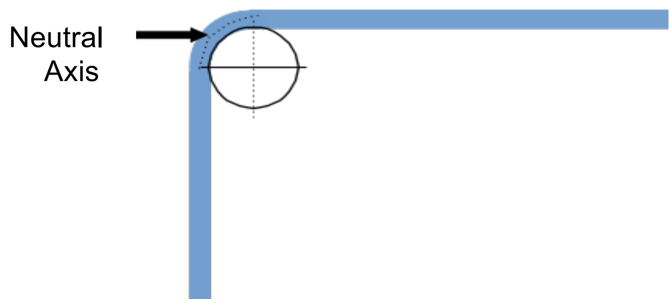
The example includes calculations of SETBACK, BEND ALLOWANCE, and BEND RADIUS). The properties of formed sheet metal won't allow us to form a perfectly straight 90º angle. We, therefore, must bend the material around a radius. Each material and material thickness will allow us to bend to a certain radius before the material fails.
The Bend Radius is the radius if the interior of the curve. Setback (SB) is the distance from the mold point to the tangent lines of the curve. Setback is calculated as Bend Radius (BR) + Material Thickness (MT). SB = BR + MT



In practical application, we select a bend radius based on the following constraints:
- The required geometric requirements of the part
- The capability of our tooling to form a radius
- The bend radius must not exceed the minimum safe bend radius for the material and its thickness.

"Safe Bend" Charts define the minimum safe bend radius for a given material grade and thickness. Bends too "sharp" for a given material and thickness risk failure of the material.

Calculating Bend Allowance
When we bend a blank, the exterior surface expands while the interior surface compresses. The center of the material's width remains neutral.



The radius to the neutral axis is our Bend Radius + ½ Material Thickness. (BR + ½ MT)

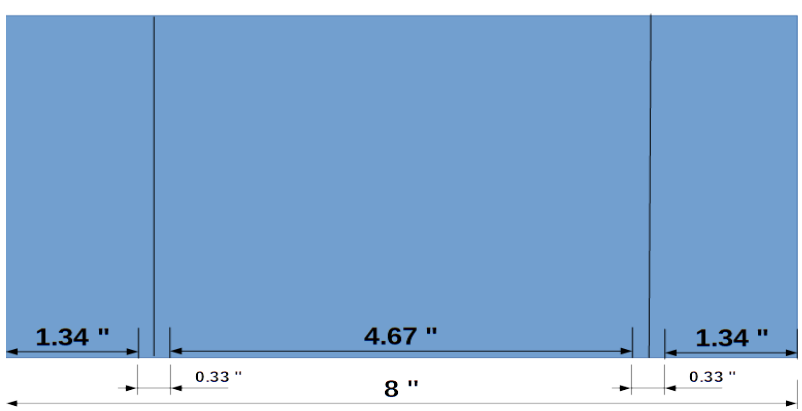
The circumference of the circle formed by the neutral axis is:
2π (BR + ½ MT).

Since our bend is a quarter circle, the formula for the neutral axis, and Bend Allowance (BA), is: 2π/4(BR + ½ MT)

To simplify the equation, we convert it to:

BA = 1.57BR + .702MT

Determining the blank size required to form our part:
Assume we want to form an open box of 12" long x 5" tall x 1.5" deep. The theoretical dimensions for the blank would be:
We must now measure the blank to the Bend Tangent Line (BTL), determine our setback, and calculate the Bend Allowance (BA) to determine the ideal size of the blank.



Assume a Bend Radius (BR) of .125 and a Material Thickness (MT) of .04.

Our Setback (SB) is determined as SB = BR + MT, therefore our Setback is

$$.125 + .04 = \mathbf{.165}$$

Subtract one Setback from each flange and two setbacks from the flat:

To determine the material width, you must calculate the Bend Allowance:

$$BA = 1.57(BR) + .702(MT)$$
$$\mathbf{BA = 1.57(.125) + .702(.04) = .224}$$

The amount of material needed for the bend is .224 inches.

The final blank width should have the following width dimensions: