Learning from Inquiry in Practice
ASP Conference Series, Vol. 436
Lisa Hunter and Anne J. Metevier, eds.

An Engineering Technology Skills Framework that Reflects Workforce Needs on Maui and the Big Island of Hawai‘i

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Abstract. The Akamai Workforce Initiative (AWI) is an interdisciplinary effort to improve science/engineering education in the state of Hawai‘i, and to train a diverse population of local students in the skills needed for a high-tech economy. In 2009, the AWI undertook a survey of industry partners on Maui and the Big Island of Hawai‘i to develop an engineering technology skills framework that will guide curriculum development at the U. of Hawai‘i – Maui (formerly Maui Community College). This engineering skills framework builds directly on past engineering-education developments within the Center for Adaptive Optics Professional Development Program, and draws on curriculum development frameworks and engineering skills standards from the literature. Coupling that previous work with reviews of past Akamai Internship projects and information from previous conversations with the local high-tech community led to a structured-interview format where engineers and managers could contribute meaningful commentary to this framework. By incorporating these local high-tech companies' needs for entry-level engineers and technicians, a skills framework emerges that is unique and illuminating. Two surprising features arise in this framework: (1) "technician-like" skills of making existing technology work are on similar footing with "engineer-like" skills of creating new technology; in fact, both engineers and technicians at these workplaces use both sets of skills; and (2) project management skills are emphasized by employers even for entry-level positions.

1. Overview of the Akamai Workforce Initiative

The Akamai Workforce Initiative (AWI)[1] partners high-tech industry, astronomical observatories, cutting-edge research, and inventive education to meet needs in astronomy, remote sensing, and other technology industries in Hawai‘i. The AWI provides training in electro-optics for a diverse student population through an innovative, culturally-relevant curriculum, designed to meet workforce needs. At the heart of the AWI are

[1] `http://kopiko.ifa.hawaii.edu/akamai/`

two internship programs that use a model developed by the Center for Adaptive Optics (CfAO) to retain and advance students into science and technology careers. The Maui Internship Program places students at Maui sites, primarily high-tech companies, for a seven-week research experience. On Hawai‘i Island, the Akamai Internship uses the same model, but places students at astronomical observatories. Through a carefully designed set of programs and activities, the AWI advances *akamai* — smart, clever, expert — students into the technology workforce on Maui, and more broadly in Hawai‘i.

The AWI is headquartered at the U. of Hawai‘i Institute for Astronomy (IfA) on Maui, and partners the IfA with the CfAO at UC Santa Cruz, the U. of Hawai‘i – Maui (formerly Maui Community College, or MCC), and the Air Force Maui Optical and Supercomputing Site (AMOS). In addition to the Akamai Internship Programs, AWI also includes the development of a new electro-optics curriculum at UH–Maui, the development of science/engineering education expertise through the Teaching and Curriculum Collaborative, and recruitment activities in Hawai‘i's high schools. These components are interwoven and all serve the goals of: preparing local students for high-tech careers; increasing the capacity of and building partnerships among the local technical and educational communities; and increasing the participation of diverse populations in technology and technology education. The Teaching and Curriculum Collaborative includes participation from Hawai‘i's early-career scientists, engineers, and educators in the Professional Development Program (PDP) developed by the CfAO and now part of the Institute for Scientist & Engineer Educators (ISEE) at UC Santa Cruz. In the PDP, engineer-educators who will teach in AWI projects develop curriculum and activities that teach students technical content and reasoning processes simultaneously, in authentic and inclusive inquiry settings. For more description of the PDP, see Hunter et al. (2008, and see also Hunter et al., this volume).

The AWI was launched in September 2007 and builds on years of partnership activities on Maui, including the Akamai Internship Program, curriculum development for MCC, and extensive partnering with industry. Past work was funded by the CfAO in partnership with MCC, the IfA, Maui Economic Development Board (MEDB), AMOS, and many industry partners. On Hawai‘i Island, the AWI is built on a long-term partnership of the CfAO, W. M. Keck Observatory, Hawai‘i Community College, U. of Hawai‘i – Hilo, and many Mauna Kea observatories.

2. Introduction

Throughout years of previous work, the Akamai Workforce Initiative has long been interested in improving students' skills in science and engineering processes, in addition to teaching them science and engineering content. In 2009 we took up a synthesis of our past work, external recommendations and others' work, and the needs and wishes of the technology communities of Maui and the island of Hawai‘i.[2] This paper reports on taking those syntheses and advancing them into a new skills framework to guide curriculum development within the internship programs and at UH–Maui.

[2]Hereafter we will refer to the "Big Island" as "Hawai‘i" and we will be clear when we refer to the entire state.

The skills that engineers and technicians employ fall on a spectrum. On one end of the spectrum, some are hands-on or purely technical skills: soldering or knowing a particular programming language, for examples. Teachers and mentors can usually imagine how to demonstrate or teach these skills; there are textbooks, lessons, or simple tasks that help. On the other end of the spectrum are engineers' reasoning skills: designing within constraints or prototyping, for examples. There is a great deal more uncertainty about how to teach these skills. Yet, most agree that these are the most critical and transferable of engineers' skills. For example, while programming languages may change, the skills of debugging and testing can take an engineer to the next generation of problems.

This paper focuses on engineering and technology skills, and even more narrowly, on the reasoning skills end of that spectrum. We will discuss the broader implications for curriculum content, student attitudes, and broader skills considerations, but let it be noted that this paper has a narrow focus on the technological reasoning skills themselves.

3. Our 2009 Skills Assessment

3.1. Inputs Into This Work

The current work is a synthesis and re-visiting of our own past work, external references, and community input. The authors first studied engineering process skills — as distinct from the process skills of scientific inquiry — when the CfAO's Professional Development Program developed education professional-development components specifically for engineers. This initial effort was led by our PDP colleagues Barry Kluger-Bell and Jason Porter (personal communication). Resources that our colleagues introduced to us then, which AWI has continued to utilize, and whose considerations significantly influenced this work, include the ABET engineering and technology accreditation criteria (ABET 2008a,b); the ITEA Standards for Technological Literacy (ITEA 2007); and the Massacusetts Technology/Engineering Curriculum Framework (Massachusetts Department of Education 2006).

When the AWI began to consider an electro-optics curriculum for the state of Hawai'i, we also consulted the National Photonics Skills Standards for Technicians (CORD 2008).

Our rich understanding of Maui and Hawai'i's technology communities, and their needs, comes from years of experience with Akamai internship projects, and interviews with engineers that partner with Akamai. Summaries of pre-2009 Akamai internship projects are available in AWI technical reports (Hunter et al. 2009 and Seagroves, Hunter, & Armstrong 2009). This prior knowledge of the types of technology work going on in the state of Hawai'i — and what is needed of interns and recent college graduates — factored significantly into this work.

3.2. The Communities Involved

For years, as part of the Akamai Internship Programs, we have sat down for meetings and interviews with Maui's and Hawai'i's companies, observatories, and other institutions to discuss appropriate internship projects and the skills undergraduate interns need to be successful. For our 2009 skills assessment, we augmented those interviews with specific questions about our putative skills framework. We would like to thank the institutions involved, which are shown in Table 1. This paper reflects significant interpretation by the authors of the community's primary-source data. While we hope we have fairly represented the thoughts of those we have worked with, this paper is the work of the AWI and should not be construed as the official position of any of the institutions.

Table 1. Companies, institutions, and observatories that contributed to this work. All of the below have hosted Akamai interns whose projects contributed to the skills inventories in Hunter et al. (2009) and Seagroves et al. (2009). Those skills inventories informed interviews for the work described in this paper. The interviews took place with all those marked (*); where interviews did not take place it was typically for scheduling/logistical reasons.

Maui	**Hawai'i**
Akimeka*	Canada-France-Hawaii Telescope*
Boeing	Gemini Observatory
HNU Photonics*	Institute for Astronomy, Hilo*
Institute for Astronomy, Pukalani	Subaru Telescope*
UH–Maui (formerly MCC)	Submillimeter Array (+ AMiBA)*
Maui High Performance Computing Center*	UH–Hilo
Northrop Grumman	W.M. Keck Observatory*
Oceanit*	
Pacific Disaster Center*	
Textron*	
Trex Enterprises*	

3.3. The Interview Handout and the Interviews

Using the engineering-education standards mentioned and cited in §3.1 and years of compiled internship skills discussed in Hunter et al. (2009) and Seagroves et al. (2009), we developed a handout which may be found in Seagroves & Hunter (2009, Appendix A). The handout was a tentative identification of the engineering technology reasoning skills that seemed to come up most frequently in our past work in these communities.

We brought this handout with us to meetings with over forty engineers at a dozen of Maui's high-tech companies and Hawai'i's observatories. During the meetings, we explained some context: that we were particularly interested in transferable engineering skills; that we were already aware of the importance of communication skills (they are already an integral part of the Akamai program); and that we were looking for the technical community's feedback on the document we had prepared. We asked them to consider what tasks and processes they themselves spend their time on, and what skills they wished entry-level people brought with them from school.

At each meeting we then had an open discussion of engineering technology skills. We took notes on the conversations and accepted written feedback from the interviewees on the handouts. The "raw data" — what was said, how many times each item came up, our notes, their written feedback on the handouts, etc. — may be found in Seagroves & Hunter (2009, Appendix B). These raw data were then manipulated to reduce the number of individual entries by grouping similar statements together. For complete transparency, every transformation from raw data to "reduced" form is documented in Seagroves & Hunter (2009, Appendix C).

Even after reducing the number of items by combining similar ones, the remaining items still needed to be placed into some broader, more abstract categories. To do this, we again revisited other skills frameworks mentioned in §3.1.

4. Engineering Technology Skills Framework

What results from this process is a categorized "framework" of engineering technology skills. As we will discuss, the recommendations that follow are not meant to stand alone. They are a framework that should be integrated with other frameworks such as those related to accreditation and institutional needs. They are meant to supplement the considerations of other resources listed in §3.1 and to draw out elements that are particularly emphasized in the local context of the institutions listed in Table 1.

The framework, shown in Table 2, consists of three major groupings. *Critical Engineering Technology Skills and Experiences* are similar to the tasks that graduates will perform in the workplace; the college curriculum is the obvious time to provide students with training and practice with these skills. *Engineers' Ways-of-Thinking* are habits that skilled engineers employ while pursuing their work; these habits should be learned and utilized in projects and assignments. *Engineers' Professional Skills* (very similar to a sub-set of ABET's "professional skills") are ways of communicating and managing technology work that must be learned in the authentic technology context.

4.1. Detailed Discussion of the Framework

We will discuss the three major groupings in the framework, the sub-groupings within each grouping, and we will briefly elaborate on each item in the skills framework.

4.1.1. Critical Engineering Technology Skills and Experiences

The first major grouping in the framework is most easily recognized as "engineering processes" or "process skills". Many curricular frameworks emphasize only the engineering design process, or draw a sharp division between engineering programs (which emphasize design) and technology programs (which do not). Yet our work in Maui and Hawai'i indicates that many "engineers" do intellectually rigorous work not usually acknowledged as part of the engineering curriculum — and likewise many "technicians" are expected to do design engineering. Indeed, our experience in these workplaces is that the divide between these two roles is not strict at all. As an example, when an observatory asks an intern to take an off-the-shelf scintillometer, which is built to measure ground-layer turbulence at airports, and make it work instead as a dome-turbulence instrument, is the intern working as a "technician" because the device is already designed, or as an "engineer" designing a new process for using the device? The processes of characterizing such a device, determining its limits, and shoehorning it into a new role do not fit easily in the engineering design process emphasized in other frameworks.

Table 2. The 2009 Akamai Workforce Initiative Engineering Technology Skills Framework. This does not stand alone but is meant to be considered in conjunction with such sources as ABET (2008a,b); CORD (2008); ITEA (2007); Massachusetts Department of Education (2006), etc. Within each sub-category, the order that items are listed in is not strict, but those that came up the most or seemed most emphasized during our interviews are higher (Seagroves & Hunter 2009, Appendices B&C).

Critical Engineering Technology Skills & Experiences	**Making Existing Technology Work (Or Work Better)** Troubleshooting Characterizing Optimizing & Improving Installing, Integrating, & Compiling Maintaining & Operating Calibrating Improvising / Devising Workarounds **Creating/Selecting New Technology** Analyzing Tradeoffs Clarifying the Problem or Need Researching Other Solutions Brainstorming Solutions Prototyping Simulating Designing Within Requirements Breaking the Problem Down Considering "Good Enough" or 80% Solutions
Engineers' Ways-of-Thinking	**Analyzing Technology as Systems** Systems Thinking Understanding/Considering Protocols, Interfaces, & Standards Understanding/Considering Processes & Procedures Considering Controls **Other Critical Thinking Skills** Lateral Thinking Estimation (Back-of-the-Envelope & Order-of-Magnitude)
Engineers' Professional Skills	**Communication** Communicating Work Informally Presenting Formally Documenting Work for Self and Team Writing for Publication and Presentation **Managing Technology Projects** Planning Estimating Effort & Time Recognizing Resources Project Management Considering Cost Constraints Breaking the Problem Down Considering "Good Enough" or 80% Solutions Prioritizing

Our framework acknowledges a distinction between engineering design and these other skills normally ascribed to technicians, but places them on equal footing as a reflection of what Maui's and Hawai'i's engineers actually do, and what they expect of entry-level hires. We believe our emphasis on this skill category — "Making Existing Technology Work (Or Work Better)" — is a unique feature of the AWI work, and we believe it would add value to any engineering or technology curriculum.

Making Existing Technology Work (Or Work Better). This set of technician-like skills includes installing technology, getting it to work and determining what it can do, and improving upon it. Nearly everyone we spoke to emphasized how ubiquitous and universal these tasks are in their work. These apply to both hardware and software contexts — for instance, "troubleshooting" is simply called "debugging" in a software setting.

Troubleshooting Troubleshooting includes determining the symptoms of a misbehaving piece of technology, and crucially, diagnosing the root cause of the trouble. We have incorporated hardware and software (debugging) flavors of the same tasks here.

Characterizing Characterizing is among the richest of the skills in the *Making Existing Technology Work (Or Work Better)* category. As in the example given above in §4.1.1, in many entry-level positions, people are asked to determine whether some piece of technology — originally designed to do X — can do Y instead. This usually means measuring what exactly the technology does, how it behaves, what its limitations are, etc. We have pulled all of that under the umbrella of characterizing. Characterizing may also include measuring the properties of a system that is somehow malfunctioning, as a pre-requisite to troubleshooting.

Optimizing & Improving Sometimes, upon characterizing a piece of technology, it is apparent that it does not perform as well as it ought or as well as would be liked. The skills of optimizing and improving are related to the skills of troubleshooting but involve working, rather than malfunctioning, technology. Here, refining and considering efficiency may become important.

Installing, Integrating, & Compiling In both hardware and software, installing elements of technology, integrating technological pieces together, and the software-specific compiling are sometimes non-trivial tasks.

Maintaining & Operating Maintaining and operating technology may include skills such as running defined startup and shutdown procedures (for both hardware and software), hardware-specific skills such as aligning, and so on.

Calibrating While running a well-defined calibration procedure may be considered part of maintaining/operating, the concept of calibration is itself important. To be able to devise a calibration (say for a new or changed piece of equipment) is a skill not necessarily "picked up" simply from running other calibrations.

Improvising / Devising Workarounds Improvising around malfunctions and limitations, and devising workarounds when a proper fix is not possible, are creative processes requiring skill, imagination, practice, and experience.

Creating/Selecting New Technology. This set of skills more closely aligns with others' recommendations on the engineering design process. The engineering design process is sometimes presented as a linear set of steps (see, e.g., Massachusetts Department of Education 2006, p. 84). Indeed, some workplaces use a fairly regimented style of engineering process, while the largest engineering firms have the resources to even define their own processes and train their own employees to work within them. However, it is also true that engineering is sometimes less linear, more iterative, and requires recognizing the skills and processes needed at any point to jump to some other point in the process.

Analyzing Tradeoffs Considering tradeoffs when designing or choosing solutions is perhaps one of the defining characteristics of engineering as opposed to science. Tradeoffs can be technological or intrinsic to the problem — there may be no way to be good at everything or satisfy all requirements equally well. Or, tradeoffs may be extrinsic and involve considerations such as the environment, impact on society, cost, or ethical considerations. Recognizing all such tradeoffs is a start; considering them and how they interact with a design's requirements and constraints constitutes "analyzing" them. In the Hawaiian context, cultural, environmental, and socio-economic considerations are worth emphasis.

Clarifying the Problem or Need Real-world problems are not always neatly defined; sometimes it takes a great deal of work just to determine what constitutes "better" in a given situation. Likewise, smaller tasks within an engineering or technological problem are not always well-defined or explicit. Determining just what is needed and determining what the relevant tradeoffs may be is included here.

Researching Other Solutions Product and market research, to determine if there are off-the-shelf solutions, and/or researching how others have designed solutions to a problem are included here.

Brainstorming Solutions Brainstorming is often characterized as generating tentative ideas and solutions without much analysis or consideration for details of constraints. From brainstormed ideas, potential solutions that are worth refining (may) emerge.

Prototyping An important skill is the ability to quickly build a model or proof-of-concept that functions — partially or fully — and allows further engineering to proceed directly on a "real" solution. Sometimes the protoype is useful only for a limited time, and informs the manufacture of the "production" model; other times, the prototype may simply grow into the final solution. Particularly at observatories, which are usually not selling products or fulfilling contracts, the latter case occurs frequently.

Simulating Similar to prototyping, it is important to be able to model or simulate aspects of a solution within hardware or software. Particularly in the case of a computer model, simulation may conserve considerable materials and effort by allowing options to be investigated and explored without building multiple prototypes.

Designing Within Requirements We do not want to give the impression that the traditional "engineering design process" defined in other standards did not come up in our interviews. On the contrary, everyone we spoke with agreed that students must learn to identify requirements, constraints, and tradeoffs, and proceed systematically through a process of proposing a solution, refining it, building and testing a prototype, evaluating the prototype, and re-iterating if necessary.

Breaking the Problem Down Novices are sometimes overwhelmed by engineering problems but, usually, such problems can be broken down into many smaller problems, each of which may be considerably simpler.

Considering "Good Enough" or "80%" Solutions In our discussions with employers, something interesting came up which does not come up in more academic treatments — the importance of determining the "80%" or "good enough" solution. By this, most engineers seem to mean the solution which does well and would take too much time, effort, or money to improve greatly upon.

4.1.2. Engineers' Ways-of-Thinking

The second major grouping in the framework is also "process skills", but less like the tasks that engineers do and more like the ways that engineers think. The major skill category here is *analyzing technology as systems*. Students and interns have difficulty knowing at what level of abstraction to view an engineering problem or an engineering system — when they need the levels of abstraction and detail that come with a layout diagram, a schematic diagram, or a block diagram, for example. Other *critical thinking* skills came up in our discussions as well.

Systems Thinking Systems thinking is a set of skills for analyzing technological systems at the proper level of abstraction or detail. There are many contexts in which one does not need to understand the inner workings of components, but it is critical to understand the roles of various components and the ways that they interact, including the system behavior that is not simply the sum of each of the parts ("emergent behavior"). Systems thinking is typically associated with a block-diagram abstraction of components' inputs, outputs, control loops, and other relationships.

Understanding/Considering Protocols, Interfaces, & Standards Part of analyzing technology with systems thinking is understanding how components of a system communicate, interface, and interact with one another. Specific communication protocols or standards are frequently required. The design of modular components that can be re-used through standardized protocols is a consideration here (both in hardware and software). These considerations apply also to how a system may interact with other systems.

Understanding/Considering Processes & Procedures Another important part of analyzing technology with systems thinking is considering whether there are specific processes and procedures that define a system's use; examples include start-up process, a shutdown procedure, a calibration sequence, etc.

Considering Controls When technology is considered at the level of systems, aspects such as feedback, open-loop and closed-loop operation, and other issues of control become important.

Lateral Thinking Sometimes more colloquially called “thinking outside the box,” lateral thinking means using an idea from a different context — either literally, or by analogy or metaphor — in the context of the current problem.

Estimating By quickly performing back-of-the-envelope and/or order-of-magnitude calculations, engineers and technicians are able to eliminate possibilities and conserve effort.

4.1.3. Engineers’ Professional Skills

The third major grouping in the framework consists of professional skills. These are not strictly technological skills, but they are extremely important to employers and an integral part of success in science and engineering disciplines. Communication skills are one important set in this group. We already knew from past experience how important skills of writing, formal presentation, informal presentation (the “elevator talk”), etc., are to employers. They did not come up in the 2009 study because they were already assumed for context. We re-insert them here so that they are not forgotten. What did come up in 2009 was the importance of the related skill of documenting.

Communicating Work Informally Reporting at routine meetings, interacting at the water cooler, and giving the “elevator talk” (quickly summarizing one’s work to a [potentially important] stranger) are all commonplace workplace events that require being comfortable with technical communication in an informal context.

Presenting Formally Likewise, presenting formally, in internal meetings, to outsiders, at conferences and meetings, etc., is an important skill.

Documenting Work for Self and Team A form of communication that came up often in our interviews was documentation. Sometimes documentation is communication with oneself — so that a problem can be returned to after a long time and one’s previous progress is preserved. But often, documentation is important for one part of a team to communicate aspects of its solution to another part of the team, or for the designers of a solution to communicate with that system’s users.

Writing for Publication and Presentation Just as formal presentation is important, so also is formal writing. As opposed to documentation, here we refer to formal writing for “outside” audiences.

Of new interest to us in 2009 was the importance of project management skills to Maui’s and Hawai‘i’s technology employers. We had assumed that “middle management” level positions required these skills but that entry-level positions did not. On the contrary, many engineers we spoke with emphasized the need for all employees to have these skills, regardless of whether they will ever formally take on the role of a project manager. Employees work on small projects that do not necessarily need the full array of project management tools, but would benefit from some of the basic tools and skills, such as defining milestones and benchmarks, and estimating effort. In addition, when employees work on large projects, they are better able to work with a project manager when they have familiarity with project management.

Planning Defining milestones and benchmarks along the process of engineering a system helps progress to be measured. In some cases, the effort and time spent on planning is recouped by the increased efficiency and more directed nature of subsequent work.

Estimating Effort & Time Being able to estimate how many people, working for how long, and at what level of commitment, will be needed for a given task is a skill that many engineers mentioned entry-level people need more experience with.

Recognizing Resources Recognizing what resources are available — in particular, who has expertise that would save time and effort, or whether off-the-shelf components would save time and effort — was emphasized as an important skill.

Project Management Employees often work with or under a project manager, and are more effective if they know some of the basic skills, tools, and terminology of project management in general.

Considering Cost Constraints Effort and time are not the only resources to consider in project management — cost is an important constraint as well.

Breaking the Problem Down Mentioned previously in §4.1.1, breaking a problem down also helps in the processes of defining milestones, estimating effort and time, etc.

Considering "Good Enough" or "80%" Solutions Mentioned previously in §4.1.1, an important project management skill is knowing when a project has progressed enough to quit, when the returns on continued effort are diminishing.

Prioritizing Given that money, time, and effort are limited resources, it is important to prioritize what is most important to get done and/or what must be finished first.

5. Discussion: Applications of This Framework

The engineering technology skills framework described in this paper was developed to inform curriculum design for a four-year electro-optics degree program at UH–Maui and for short courses and activities associated with the Akamai internship programs. Early-career scientists and engineers who participate in the Professional Development Program (Hunter et al. 2008, and see also Hunter et al., this volume) think about what skills are important to teach and support in the activities they lead; for those PDP participants who teach in AWI venues, this skills framework is meant to guide their thinking. So, in this section we discuss the applications of the framework.

We propose that the *Critical Engineering Technology Skills and Experiences* (§4.1.1) should be tasks, projects, and assignments that students engage with throughout an engineering or technology curriculum. No single assignment needs to address all (or even many) of these items; indeed it is likely better for a particular activity to have a tight focus. For instance, a course in optics could include an assignment to align and characterize a typical laboratory optical bench; a course in data analysis could include an assignment to design an automated software pipeline to perform routine reduction and analysis of detector/sensor data.

We propose that the *Engineers' Ways-of-Thinking* (§4.1.2) are engineering skills that should be explicitly taught somewhere in the curriculum and then reinforced throughout. While some standalone assignments related to these skills may be appropriate, we recommend these skills should be necessary for success within the projects and activities that come under *Critical Engineering Technology Skills and Experiences*. For instance, in order to characterize an adaptive optics system, students should consider whether they need to understand in great detail the electronics of every component, or whether a block diagram understanding of the relationships between the wavefront sensor, computer, and deformable mirror in closed-loop operation is appropriate.

The *Engineers' Professional Skills* (§4.1.3) are difficult enough, and different enough, from technological skills that they warrant being treated separately. We recommend explicit instruction in communication skills and project management skills. Indeed, the Akamai Internship Program has for years had a concurrent, separate, but well-integrated Science/Engineering Communication course. "Well-integrated" is an important and difficult point. While these skills warrant separate treatment, we do not advocate that student work in these areas be completely divorced from other student work. That is, we do not recommend a project management task (e.g., a Gantt chart) for its own sake, or a writing or presentation assignment for its own sake. Rather, we recommend that these "layers" be added to the first category of projects and activities over time. By the time students are near graduation, "capstone"-like experiences should require project management, writing, and presentations, as well as a comprehensive suite of technology skills.

6. What Must Be Considered In Addition to This Framework

This proposed framework is not all-inclusive and does not stand alone. It was originally designed to be a focus on the reasoning process skills of engineers. With this initial focus we discovered the importance of the "technician-like" skills that are de-emphasized in engineering design frameworks. In response to emphasis from the Maui and Hawai'i communities, this framework also expanded beyond strictly technological skills to include some professional skills. However, the study remains tightly focused and there are a number of other considerations that must be brought to bear in any serious curriculum development work.

6.1. Content

The first, most obvious category of considerations missing from this framework is content. This framework makes no attempt to define which programming language should be taught, or what optical principles are the most important, and so on. On the one hand, we believe that a deep focus on engineering and technology skills will improve students' abilities to adjust to rapidly-changing technology — making specific choice of content less critical to their future success. But on the other hand, we still believe it is the responsibility of any program to continually improve and update to provide students with current, relevant technology experiences.

6.2. Necessary Pre-Requisite Math and Science

Likewise, this framework has little to say about the necessary grounding in math and science that students need. As much as possible, engineering technology programs should try to influence the design of these other courses so that they also emphasize reasoning skills.

6.3. Other Professional Skills

While our framework has called out two sets of important professional skills (communication and project management), we do not mean to give the impression that this is a comprehensive set. The other so-called ABET "professional skills" — an understanding of ethics, an understanding of the broader cultural, societal, economic, and environmental impacts of engineering, and teamwork, are critically important. While the broader impacts of an engineering project can, in principle, be treated within our skill of "analyzing tradeoffs", we applaud the ABET criteria for calling these issues out separately. For more on the ABET professional skills, see ABET (2008a,b) and Shuman, Besterfield-Sacre, & McGourty (2005).

6.4. Attitudes

Many engineers that we spoke to emphasized the importance of attitudes in addition to skills. One commented that he could teach skills, but only if the intern was motivated and wanted to learn. The distinction between some skills and attitudes is difficult to discern; the ABET criteria discuss ethics and teamwork as skills, while our interviews revealed "responsibility" and "teamwork" as responses for attitudes.

It is worth considering how to build — and perhaps more importantly, how to maintain — positive and productive attitudes when designing a curriculum. Presumably students enter engineering technology programs with some interest, motivation, and enthusiasm to learn — else they might have chosen a different program. Programs should consider how students might maintain those attitudes in the face of difficulty. Other attitudes — maturity, creativity, perseverance, ownership, responsibility, thoroughness, and a sense of self or identity as an engineer — may not be present in students when they enter a program but should be built up for students to succeed and be retained. Programs should adopt a "growth mindset" (Dweck 2006) about their students — the notion that their skills and attitudes can be built up and improved rather than being intrinsic and fixed — and project such a mindset to the students themselves.

7. Discussion: Limitations of this Framework

A striking feature of this skills framework is that it seems to place "technician-like" and "engineer-like" skills on equal footing. This feature is not present in other curricular frameworks. Yet in our conversations with over forty engineers at a dozen of Maui's high-tech companies and Hawai'i's observatories, there was broad consensus that employees need to be familiar with both these sets of skills and need to able to move fluidly between tasks in either grouping. Here we briefly discuss possible reasons for the discrepancy between the Akamai community's perception of the technician-engineer dichotomy and the more traditional view.

First, our own biases are no doubt coming into these discussions. The Akamai programs have, for years, advocated for "entry-level" positions both for *university-trained* and *community-college-trained* students. Our broad concept of what constitutes "entry-level" has probably led to some conflation of positions typically for two-year graduates and positions typically for four-year graduates. The companies and institutions we partner with are typically supportive of our workforce-development efforts and so may also have broad construals of "entry-level."

But, we also heard time and again that *both engineers and technicians* perform all these tasks. Therefore it is not simply the case that we have just conflated two-year technicians with four-year engineers; the employers themselves are telling us that everybody has to be able to do all these jobs (to some extent).

So this leads us to another consideration: On average, the companies and observatories we have been working with are relatively small firms, and do not mass-market or mass-manufacture products for sale. Instead, they are concerned with operations and research (e.g., observatories, contractors operating defense installations) or with research and development (e.g., contractors developing for defense or energy applications). In these settings, with fewer people and with fluid roles, the lines between technical operations/maintenance and engineering design become blurred. Perhaps this is easiest to see in the observatory setting. An observatory must be maintained — "technician-like" — but also must be improved upon and upgraded — "engineer-like" — and often there is a very small staff handling all these tasks.

At larger firms and/or those with a more direct product-manufacture mandate (say, large computer manufacturers, software coorporations, or car companies) it is likely there is a more strict hierarchy between engineers and technicians.

In addition, the largest engineering design firms even define their own engineering processes internally.

8. Summary

We have presented our synthesis of engineering and technology skills relevant for college-level study, specifically situated in the context of high-tech employment on Maui and Hawai'i. However, since we have not discussed any particularly specific technology content, much of this framework should be applicable to other settings. The general method of integrating disparate inputs into the framework should apply.

In particular, we have found that "technician-like" skills have been neglected in other treatments; this sets up a stricter dichotomy between engineering programs and technology programs than is reflected in the "real-world" workplace setting. Possibly this finding is related to the relatively small size of engineering firms and observatories on Maui and Hawai'i and may not reflect parity between engineers and technicians across settings.

Also, we have found that communication skills and project management skills, which are already emphasized in existing curricular frameworks, are nevertheless still important points for improvement in the eyes of employers.

Acknowledgments. We wish to thank the companies and institutions listed in Table 1 for years of hosting and mentoring Akamai interns, and for providing their perspectives and feedback on this work (but errors or mischaracterizations are solely the responsibility of the authors). This work has been supported through funding from the

National Science Foundation Center for Adaptive Optics (NSF #AST-9876783), grants from the National Science Foundation and the Air Force Office of Scientific Research (NSF #AST-0710699 and #AST-083605), and funding from the University of Hawai‘i.

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