Technical Report 3:
An Engineering Technology Skills Framework that Reflects Workforce Needs

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1. Overview of the Akamai Workforce Initiative

The Akamai Workforce Initiative (AWI) 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. 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 two internship programs that use a model developed by the Center for Adaptive Optics 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 University of Hawai‘i Institute for Astronomy (IfA) on Maui, and partners the IfA with the Center for Adaptive Optics (CfAO) at UC Santa Cruz, the University of Hawai‘i – Maui Community College (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 MCC, 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 AWI was launched in September 2007 and builds on years of partnership activities on Maui, including the Akamai Internship Program, curriculum development, 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, University of Hawai‘i – Hilo, and many Mauna Kea observatories.

2. Introduction to Technical Report

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.[1] This report gives the status of that synthesis.

The skills that engineers 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. Figure 1, reproduced from the document used in our 2009 interviews, illustrates this spectrum.

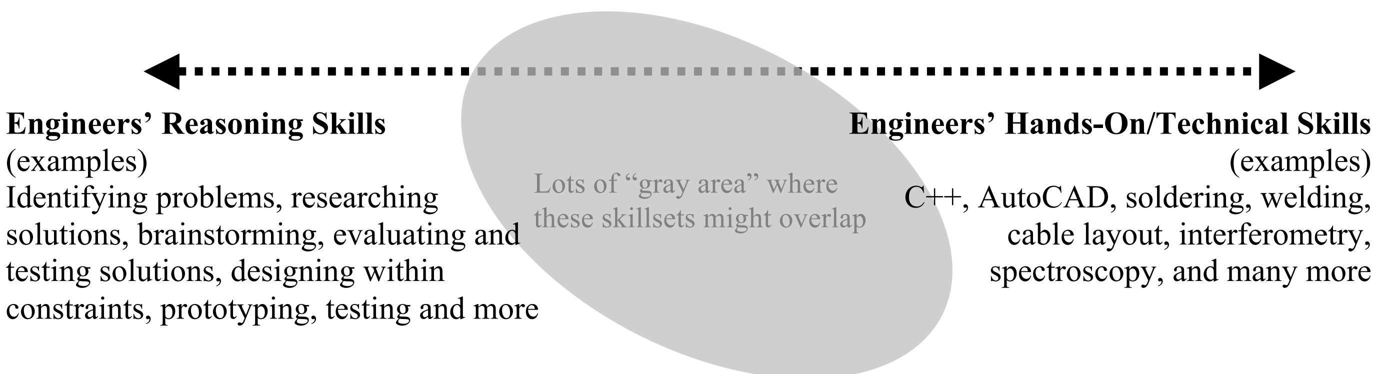

Figure 1: A spectrum of engineering skills.

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

3. Our 2009 Skills Assessment

3.1. The Communities Involved

The authors wish to thank the technology companies, academic institutions, and observatories that contributed to this work. They have hosted Akamai interns in the past, and/or met with us for interviews in 2009. It should be stated that our 2009 interviews were performed in a casual manner, with groups of engineers, with no effort to find the consensus or "official" opinion of a workplace.

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

This report reflects significant interpretation of the community's primary-source data by the authors. While we hope we have fairly represented the thoughts of those we've worked with, this report is the work of the AWI and should not be construed as the official position of any of the below-mentioned institutions.

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

Table 1: Companies, institutions, and observatories that contributed to this work. All of the above have hosted Akamai interns whose projects contributed to the first two AWI technical reports[i,ii] and interviews for this 2009 work took place with all except those in *italics* (typically for scheduling/logistical reasons).

3.2. Inputs Into This Work

The current work is a synthesis and re-visiting of disparate past work and external references. The authors first studied engineering process skills – as distinct from the process skills of scientific inquiry – when the CfAO's (now ISEE's) Professional Development Program[iii] developed educator-professional-development components specifically for engineers. Resources that we and our colleagues encountered then, which AWI has continued to utilize, and whose considerations significantly influenced this work, include:

- The ABET engineering[iv] and technology[v] accreditation criteria
- The ITEA *Standards for Technological Literacy*[vi]
- The Massacusetts Technology/Engineering Curriculum Framework[vii]

In a more specific content area, when the AWI began to consider an electro-optics curriculum for the state of Hawai'i, we consulted the *National Photonics Skills Standards for Technicians.*[viii]

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 Akamai-partner engineers. Summaries of pre-2009 Akamai internship projects intern host/mentor contributions to this skills assessment are available in previous AWI technical reports.[i,ii] 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.

3.3. The Interview Handout and the Interviews

The above considerations fed into a handout we produced, which is included here as Appendix A.

We brought this handout with us to meetings with over forty engineers at a dozen Maui high-tech companies and Hawai‘i 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 their 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. This report summarizes both their feedback and our own notes, so "counts" are not strictly rigorous, but some interviewees primarily wrote while others primarily spoke, so we hoped to capture all the information.

The raw data – in the form of what was said and approximately how many times each item came up – are included here as Appendix B.

The raw data were then manipulated to reduce the number of individual entries by grouping similar statements together. Those groupings are included here as 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 referred to the inputs described in 3.2.

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.

This framework of engineering technology skills draws on all our previous work and the 2009 interviews with Maui and Hawai‘i engineers. It is meant to help with curriculum design. The framework 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 ABET's "professional skills"[ix]) are ways of communicating and managing technology work that must be learned in the authentic technology context.

Critical Engineering Technology Skills and Experiences	
Making Existing Technology Work	**Creating / Selecting New Technology**
Troubleshooting	Analyzing Tradeoffs
Characterizing	Clarifying the Problem or Need
Optimizing & Improving	Researching Other Solutions
Installing, Integrating, & Compiling	Brainstorming Solutions
Maintaining & Operating	Prototyping
Calibrating	Simulating
Improvising / Devising Workarounds	Designing Within Requirements
	Breaking the Problem Down
	Considering "Good Enough" or 80% Solutions

Engineers' Ways-of-Thinking	
Analyzing Technology as Systems	**Other Critical Thinking Skills**
Systems Thinking	Lateral Thinking
Understanding/Considering Protocols, Interfaces, & Standards	Estimation (Back-of-the-Envelope & Order-of-Magnitude)
Understanding/Considering Processes & Procedures	
Considering Controls	

Engineers' Professional Skills	
Communication	**Managing Technology Projects**
Communicating Work Informally	Planning
Presenting Formally	Estimating Effort & Time
Documenting Work for Self and Team	Recognizing Resources
Writing for Publication and Presentation	Project Management
	Considering Cost Constraints
	Breaking the Problem Down
	Considering "Good Enough" or 80% Solutions
	Prioritizing

Table 2: The 2009 AWI Engineering Technology Skills Framework

4.1. Detailed Discussion of the 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 Hawaiʻi 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 make an off-the-shelf scintillometer, which is built to measure ground-layer turbulence at airports, 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.

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 Hawaiʻi's engineers actually do, and what they expect of entry-level hires. We believe our emphasis on this skill category – "Making Existing Technology Work" – 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. This set of technician-like skills includes installing technology, getting it to work and determining what it can do, and improving upon it. Those we spoke to emphasized the ubiquity of these tasks. These apply to both hardware and software contexts – for instance, "troubleshooting" is simply called "debugging" in a software setting.

Among the richest of these skills is *characterizing*. As in the above example, 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.

Creating / Selecting New Technology. This set of skills more closely aligns with others' recommendations on the engineering design process. Of particular importance: clarifying an ill-defined task or problem, and considering tradeoffs when designing or choosing solutions. Tradeoffs can be technological or intrinsic to the problem, but they may also be extrinsic and involve considerations such as the environment, impact on society, cost, or ethical considerations.

Something interesting that came up in our discussions with employers, which does not come up in more academic treatments, is the importance of determining the so-called "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 or "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. Students and interns have difficulty knowing when they need the levels of abstraction and detail that come with a layout diagram, a schematic diagram, or a block diagram. Systems thinking is typically associated with a block-diagram abstraction of components' inputs, outputs, control loops, and other relationships. Components' interactions may involve specific interfaces or communication protocols, or specific processes and procedures. The design of "modular" components that can be re-used through standardized protocols is a consideration here (both in hardware and software).

Another interesting engineering way of thinking is sometimes called "lateral thinking" or more colloquially "thinking outside the box". By this, most engineers mean using an idea from a different context – either literally, or by analogy or metaphor – in the context of the current problem.

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.

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 don't 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, employees often work with or under a project manager, and will be more effective if they know some of the basic skills, tools, and terminology.

4.2. Relationships Between the Groupings in Curriculum Use

We propose that the *Critical Engineering Technology Skills and Experiences* should be tasks, projects, and assignments that students engage with throughout the 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.

The *Engineers' Ways-of-Thinking* are science/engineering skills that should be taught somewhere in the curriculum and then reinforced throughout. While some standalone assignments related to these skills may be appropriate, we recommend they be necessary for success within the first grouping of projects and activities. 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* 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 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.

4.3. What Else Must Be Considered

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 Hawaiʻi 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.

4.3.1. 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, we still believe it is the responsibility of any program to continually improve and update to provide students with current, relevant technology experiences.

4.3.2. 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.

4.3.3. 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, teamwork, etc., 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.

4.3.4. 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" (the idea that skills and attitudes can be built up and improved rather than being intrinsic to the person and fixed[x]) about their students and project such a mindset to the students themselves.

5. 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 the particularly specific relevant 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.

Also, we have found that communication skills and project management skills are not only important to employers, but also still in need of improvement, despite their emphasis in existing curricular frameworks.

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Appendix A

Document used to conduct interviews with and collect data from Maui and Hawaiʻi engineers

Your name

Your company/institution

Today's innovative education in engineering and technology focuses on teaching students to "think like engineers". But what does that mean to you?

Attitudes of good engineers & engineering technicians

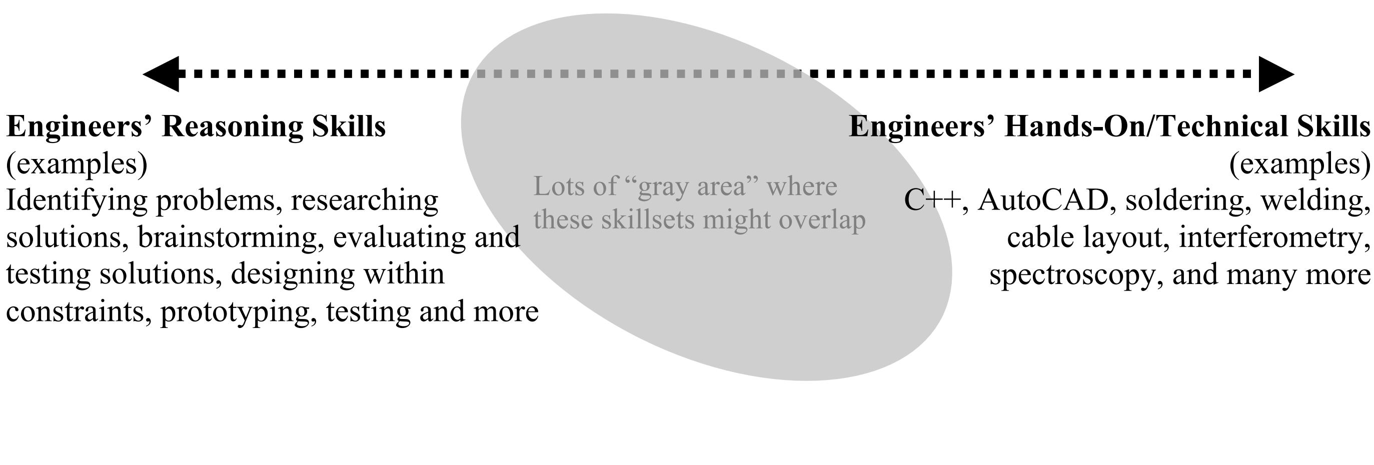
First, we want to acknowledge that many firms are looking for people with the following attributes:

Motivation   Interest   Enthusiasm   Being proactive   "Teachability"

Do you think there are attitudes we are missing?

Thought processes of good engineers & engineering technicians

Next, we are particularly interested in getting your perspectives on *reasoning skills*, as compared to *purely technical or hands-on skills* (certainly important too), but we recognize that there's a lot of gray area in between. Here's what we mean by that:



Appendix A

Document used to conduct interviews with and collect data from Maui and Hawai‘i engineers

We have identified a few particularly rich and deep ways that engineers think about problems, and we are interested in your feedback. You can circle things that particularly resonate with you, write in things that you think are missing, or just talk to us about your reactions.

Thought processes of good engineers & engineering technicians

Setting up & testing *which might also include* Aligning Troubleshooting Documenting Calibrating Characterizing Integrating Measuring Diagnosing Maintaining Operating Compiling Installing Debugging	**"Systems Thinking"** *which might also include* Processes Controls Components Plugins Subprograms Interfaces Standards Protocols
Optimizing / improving *which might also include* Evaluating Refining Troubleshooting Diagnosing Documenting Calibrating Characterizing Analyzing Recognizing trade-offs Considering efficiencies Processes Refactoring Debugging	**Designing within requirements** *which might also include* Clarifying the problem/need Researching other solutions Identifying constraints, requirements, trade-offs Brainstorming solutions Prototyping Evaluating solutions Considering tradeoffs Testing Documenting

Appendix B

Raw data from Akamai engineer interviews

The raw data are tallies from the handouts returned by interviewees plus our own notes from the conversations – simple counts of the number of times various ideas came up.

Items Mentioned or Discussed in Interviews	#[a]
Skill Category: Setting Up & Testing	0
aligning	2
troubleshooting	21
documenting	23
calibrating	7
characterizing	9
integrating	6
measuring	12
diagnosing	9
maintaining	4
operating	3
compiling	5
installing	2
debugging	11
Added by others in this category	
simulating	1
[product] research, market surveys	1
limitations	1
procedures	3
configuration control (always able to get back to original)	3
Skill Category: Optimizing / Improving	2
evaluating	6
refining	2
troubleshooting	11
diagnosing	8
documenting	15
calibrating	2
characterizing	7
analyzing	12
recognizing trade-offs	10
considering efficiencies	2
processes	2
refactoring	0
debugging	4
Added by others in this category	
innovating	1
simulating	1
"root cause analysis"	3
considering what is good enough / 80% solutions	3
improvisation / workarounds	3
soliciting users' needs	2

Items Mentioned or Discussed in Interviews	#[a]
Skill Category: "Systems Thinking"	5
processes	16
controls	7
components	7
plugins	4
subprograms	0
interfaces	6
standards	8
protocols	6
Added by others in this category	
usability	1
simulating	4
analyzing	1
bottom-up vs top-down in software / architectures	4
big picture vs detail	8
documenting	2
understanding interactions among/between components	2
modularity	2
Skill Category: Designing Within Requirements	4
clarifying the problem/need	15
researching other solutions	14
identifying constraints, requirements, tradeoffs	18
brainstorming solutions	15
prototyping	11
evaluating solutions	8
considering tradeoffs	11
testing	8
documenting	15
Added by others in this category	
project management	5
estimating effort/time	15
cost constraints	5
bottom-up vs top-down in software	2
simulating	1

Appendix B

Raw data from Akamai engineer interviews

Items Mentioned or Discussed in Interviews	#[a]	Items Mentioned or Discussed in Interviews	#[a]
Other skills that came up but not in a particular category		*Attitudes[c]*	
communication[b]	11	motivation	2
ability to learn from scratch	1	interest	1
seek out and accept others ideas	3	enthusiasm	2
get unstuck	4	being proactive	0
principles seen in one context -> other context	5	"teachability"	0
break problem down	4	*Added by others in this category*	
planning	8	even-keel / "control of emotions"	4
flowcharting & timelining	3	"common sense"	4
knowing what resources are available	4	maturity	1
who can help	4	inquisitive	2
prioritizing	1	creativity	2
admin associated with work (paperwork, rules, forms)	1	perseverance	3
"all of the above" (skills that were on the interview worksheet)	4	teamwork	3
back of envelope estimation / order of magnitude estimation	5	sense of self	2
toolkit of techniques	2	ownership	2
contingency planning / risk analysis	4	responsibility	4
		thoroughness	1

Table 3: Raw data from interviews with Akamai engineers.

Notes: (a) The number represents the sum of written responses from those interviewed plus notes taken by the authors during the interviews. This is because not all those interviewed gave written responses if they preferred to just talk, and the authors decided strict rigor was less important than candor from the engineers. (b) We deliberately said, as context, that the Akamai program already emphasizes communication in many ways. We believe that if we had not given this context, communication would have come up much more frequently (as did documentation). (c) In the interest of time, we often skipped much discussion of attitudes so that we could get to the skills.

Based on our notes and recollections from the interviews, and our knowledge of engineering processes and skills, items that seemed very similar were combined so that our final product would not list too many individual entries.

In the table below, items on the left are concepts composed of the interview items on the right. In special cases, items mentioned in the interviews were distributed among more than one "final" item. The items on the left make up our final recommendations and are further categorized in the main text of the report. This table is simply included so that readers can ascertain what raw data went into each of our recommendations.

Combined Item	**Interview Items that Comprise the Combined Item**
documenting work for self & team	documenting + configuration control (always being able to get back to the original)
troubleshooting	troubleshooting + diagnosing + root cause analysis + debugging
characterizing	characterizing + limitations + ½ (measuring + testing + evaluating + analyzing + evaluating solutions)
analyzing tradeoffs	recognizing tradeoffs + considering tradeoffs + ½ (identifying constraints, requirements, tradeoffs)
clarifying the problem or need	clarifying the problem/need + clarifying an ill-defined task + soliciting users' needs + ½ (identifying constraints, requirements, tradeoffs)

Appendix B
Raw data from Akamai engineer interviews

Combined Item	Interview Items that Comprise the Combined Item
optimizing & improving	optimizing / improving + refining + considering efficiencies + ½ (measuring + testing + evaluating + analyzing + evaluating solutions)
understanding/considering processes & procedures	processes + procedures
understanding/considering protocols, interfaces, & standards	protocols + interfaces + standards
researching other solutions	product research / market surveys + researching other solutions + seeking out others' ideas
planning	planning + flowcharting & timelining + contingency planning / risk analysis
estimating effort / time	estimating effort / time
brainstorming solutions	brainstorming solutions
systems thinking	systems thinking + big picture vs. detail + understanding interactions among/between components + components + plugins + modularity + bottom-up vs. top-down in software/architectures
installing, integrating, & compiling	installing + integrating + compiling
prototyping	prototyping
maintaining & operating	aligning + maintaining + operating
calibrating	calibrating

Combined Item	Interview Items that Comprise the Combined Item
recognizing resources	knowing what resources are available + knowing who can help
considering controls	controls
simulating	simulating
project management	project management
lateral thinking	principles seen in one context → other context
considering cost constraints	cost constraints
back of envelope estimation / order of magnitude estimation	back of envelope estimation + order of magnitude estimation
designing within requirements	designing within requirements
breaking the problem down	break the problem down
improvising / devising workarounds	improvisation/workarounds
considering “good enough” or 80% solutions	considering what is good enough + 80% solutions
prioritizing	prioritizing

Table 4: How items from the raw data were “lumped” together into fewer items.