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An Industry/University Forum on
Graduate Education for 21st Century Electronics
Purdue, West Lafayette
May 9, 2017

**Motivation:**

The NEEDS initiative, which includes teams at Purdue, Berkeley, MIT, and Stanford, recently hosted a forum on graduate and continuing education in electronic materials, devices, circuits, and systems. Advances in electronics have transformed our world, but today, electronics is changing. Electronics companies are exploring new ways to advance computing as they also search for new markets and opportunities. Many more companies make use of electronics, and more and more of them are becoming technology developers themselves. Electronics now engages a much wider range of industries and societal challenges than in the past and is enabled by a much broader range of science. "Electronics" has become a pervasive, cross cutting technology. (The term "electronics" is used here broadly to include MEMS/NEMS, photonic, optoelectronic, spintronic and nanomagnetic materials and devices as well as electronic devices.) As electronics changes, it is time to think about how education should change to prepare students and working engineers for an era of rapid change and great opportunities. The purpose of this forum was to begin a discussion on these important topics, so that specific, next steps can be defined.

**Key conclusions:**

Although students, engineers in industry, and faculty provided different perspectives, the overall conclusions were quite consistent.

1) There will be great opportunities in electronics research and development that is system or problem-driven. Hardware engineers who understand software and systems and who are passionate about building things will have tremendous opportunities.
2) Understanding fundamentals (such as math, computer science, physics, materials science, chemistry, electrical engineering) is essential for a productive career in rapidly changing technologies, and the list of fundamental topics that need to be understood is growing as the applications that drive electronics broaden. Developing a deep understanding of fundamentals should be the top priority of a university education. Its importance to a successful career in technology cannot be overstated.
3) Familiarity with rapidly changing current and emerging technologies is also needed. A life-long career in technology development can be rewarding for those who can use their knowledge of fundamentals to quickly become proficient in trending technologies.
4) To succeed in industry (or graduate school or academia for that matter), fundamental knowledge and understanding of currently trending technologies must be complemented by a set of technical and soft-skills such as specific software and data acquisition and analysis skills, an ability to communicate to experts and non-experts, talent for working in multi-disciplinary teams, an understanding of IP issues, etc. Many of these skills can be learned on the job, but students should get started on developing some critical skills, such as effective communication, while in school.
5) Finally, technology stars have a set of personal characteristics that separate "drivers" from "passengers". These include ethics and integrity, being results-focused, striving to always over-deliver, passion for the work, driving change rather than just trying to keep up. Students expressed a desire for more guidance on how to prepare to succeed and excel in careers in industry.

**Session 1: Perspectives from Industry**
Speakers from several companies provided perspectives on 21st century electronics. Analog Devices, Intel, Micron Technologies, NXP Semiconductors, Qorvo, Synopsys, Texas Instruments, and Western Digital were represented; some presented brief remarks and all participated in the discussions. Speakers introduced their companies, briefly described their current focus, and some new opportunities on the horizon. Speakers then discussed the knowledge and skills students need to be successful in a new era of electronics as well as the challenges that working engineers face in today's rapidly changing environment.

Summaries of each presentation can be found in Appendix 1. Because a broad range of companies was represented, different perspectives were expected, but several points were stressed repeatedly.

- The importance of a strong grounding in fundamental science, computer science, mathematics, statistics, numerical analysis, materials science, solid-state electronic devices, circuits, and systems, etc.
- The requirement to be a life-long learner who uses a base of fundamental understanding to learn the latest technologies du jour.
- The importance of technical and non-technical success skills beginning with being able to communicate to both experts and non-experts, an ability to work in teams, possessing good software, data analysis, and computing skills, etc.
- Beyond fundamental knowledge and skills, personal attributes such as passion for the work, perseverance, resilience, ethics, an ability to thrive in a dynamic, uncertain environment, a focus on execution, a desire to drive change, a commitment to over-deliver, etc.

As academics, we are challenged to provide students with a deep understanding of fundamentals that will provide them with an enduring foundation for a career. It's also important to acquaint students with current topics that will help them land their first job. Doing both well is not easy, but we should also do more to help students acquire the additional hard and soft skills they need to succeed in industry. Their education should provide them with experiences that help them start on a path to becoming technical leaders. The strong message from our colleagues in industry is "don't compromise on fundamentals," but try to provide students with more of the skills and experiences they will need to succeed and thrive in industry.

**Session 2: Perspectives from Students**
NEEDS students from Berkeley, MIT, Purdue, and Stanford provided their perspectives on the results of a pre-forum survey of current and former NEEDS students, colleagues in industry, and faculty. The student-led discussion went through a subset of the questions asked on the survey.

See Appendix 2 for a summary results and the subsequent discussion and for the complete survey results. Some of the key points from the survey and discussion are listed below.

- Taking classes and doing thesis research are complementary aspects of graduate education. Course work provides the solid understanding of fundamentals needed for a career at the forefront of rapidly changing technology. Challenging, cutting-edge thesis research provides an opportunity to develop deep expertise, acquire specific technical skills, and to hone problem solving, communication, and other soft skills.
- Faculty should take a more active role in encouraging students to take the kinds of courses, short courses, skills training, etc. that will better prepare them for careers in either industry or academia.

- More flexibility in choosing courses should be provided (especially to take courses outside of the department). Universities should learn now to take better advantage of the growing number of on-line courses. The recent expansion of the "flipped mode" of teaching at Purdue was cited as one example.
- More collaborative, multi-disciplinary, team-based research could provide students with opportunities to develop the kinds of skills successful engineers in industry need.
- Students appreciate being connected to industry – both through internships and industry-related projects.
- Software skills are essential for success in industry, and students and faculty should understand that only being proficient in MATLAB is not enough.
- A Ph.D. typically takes 5-6 years to complete (even if the student begins with an MS degree), and it was generally felt that this should be shortened some. It does, however, seem to take about 5 years for a fresh BS student to acquire the knowledge, skills, and experiences needed for a Ph.D. to be ready to enter industry or academia and quickly contribute.
- The key to designing an excellent graduate program is finding the right balance between: 1) Technical depth and breadth in fundamentals, 2) Familiarity with current, trending technologies, 3) Additional technical (e.g. SW) and non-technical (e.g. communications, collaboration) skills, and 4) Acquiring key success factors such as general problem-solving skills, appreciating the importance of ethics, perseverance, doing more than expected, driving change rather than adapting to it, etc.

**Session 3: Perspectives from Faculty**

Because the sessions from industry and students stimulated so much discussion, we ran short of time for a formal session on faculty perspectives. One topic of brief discussion was: "Given the increasing amount of high-quality educational materials available online, how should the on-campus experience change? One possibility is to make the on-campus experience more "hands-on." Prof. Luca Daniel of MIT briefly discussed how his work to make the electromagnetics course at MIT more hands on has turned around a trend of declining enrollments. Another possibility is to focus the on-campus programs more on the soft-skills students need to succeed and use on-line courses (such as nanoHUB-U) to convey fundamentals.

Faculty were gratified to see that the importance of fundamental, long-lasting knowledge is widely appreciated, but the list of fundamental topics that need to be understood was daunting, and it is continually growing. It does not seem to be possible to acquire the fundamental knowledge needed within the confines of an MS program, and probably not even in a Ph.D. degree program. Perhaps it is time to re-think how we teach fundamentals and look for a better way.

Acquiring the additional technical and soft skills needed to succeed in industry or academia should be part of a graduate education experience. Our colleagues in industry described the skills that engineers need to succeed in industry. With the exception of deep expertise in a topic, which appears to be significantly more important for success in academia, the success skill set for graduate school, industry, and academic are essentially identical. Many resources are available on-campus to provide student with opportunities to learn and develop these skills, but it can be hit or miss, and some students can fall through the cracks. In addition to fundamental knowledge that students acquire in courses and the deep expertise they acquire in thesis research, faculty should think about how to structure graduate programs so that students acquire a strong set of success skills.

Recently, the Purdue faculty have been discussing the creation of the new, professional masters degree program. (The term. "professional," is used to describe a program for students who do not intend to Purdue a Ph.D. The program would be designed to address some of the issues raised in this forum: 1) The need to better combine technical depth and breadth, 2) The inclusion of multi-disciplinary, team projects as part of the research experience, and 3) the development of students' technical and soft skills. We believe that this could also be an opportunity to increase the number of U.S. students in the hardware side of electrical engineering, and that it would also benefit Ph.D. students. Time did not permit a discussion of this topic, but informal conversations suggest that there is interest in such a program at several companies.

**Next Steps:**

The characteristics of a strong materials and devices graduate program for 21st Century Electronics were listed in "Key Conclusions" on page 1. The broad support for these pillars of a graduate education by students, faculty, and industry suggest that while they may sound like "motherhood and apple pie", they are the right components of an excellent education. As one of the participants from industry noted, "there's a lot right with current graduate program", so we should make changes cautiously. Another participant from industry said: "We need people who understand fundamentals. You cannot highlight this in your document enough!" Electronics is changing, but most graduate programs are much like they were 30 years ago. It's time to consider some changes to make careers in electronics technology an option that is as significant and exciting for the next 30 years as it has been for the past 30.

Listed below are some specific steps that should be taken.

1) Identify the fundamentals that a student, engineer, or faculty member working on electronic materials and devices today should possess as a base for a career in rapidly changing technologies. Since the list is likely to be more than can be completed in a typical degree program, this may entail re-thinking how we teach fundamentals.
2) Identify a set of industry partners who will act as advisors and champions within their companies.
3) Develop and deploy a set of online courses directed at the fundamental and broader knowledge and skills that will help graduate students and working engineers excel in 21st Century electronics.
4) Offer a "Technology Maestro Certificate" to students who take proctored exams and pass a minimum number of on-line courses appropriately distributed between fundamentals, trending topics, and skills. (Technology maestros have technical depth in a specific field, but also the breadth and skills necessary to work with and lead diverse, multi-disciplinary teams of technology developers.) The goal would be to develop a certificate program attractive to working engineers as well as to Ph.D. students seeking the fundamental knowledge, technical breadth, and related skills needed to stand out as 21st Century technology developers. To be successful, this program should include key courses from a number of universities, and it will need to be defined in close collaboration with partners in industry so that completing the program is perceived of as a significant accomplishment of high value in industry as well as academia.
5) Define and launch an on-campus, Technology Maestros professional Masters program. This program would complement the on-line education that students acquire in the certificate program with traditional on-campus courses, hands-on courses, multi-disciplinary team projects, and other activities that develop true Technology Maestros. Entrance to the program would be restricted to students who do well in the online program. Prior to arriving on campus, students would have successfully completed a significant portion of the masters program, so that the program could be completed in one year on campus.

**Appendix 1: Perspectives from Industry**
Some key points made by the speakers are summarized below. (The presentation files are available at https://nanohub.org/groups/needs/grad_ed_forum_2017).

**Dr. Srikanth Krishnan: Texas Instruments**
Dr. Krishnan, who leads the Reliability Group at TI began by summarizing TI's current business and future opportunities. In looking at 21st Century Electronics, he sees more coupling of analog functions with ultra-scaled digital CMOS, the likely prospects for breakthroughs in power electronics, and the need to address challenges in thermal dissipation, flexible electronics, sensors and actuators. An increasingly important factor is cost effective packaging that maintains high bandwidth, high power efficiency, good thermal dissipation, and reliability. He discussed specific challenges in global interconnects, power delivery, materials and interfaces, and thermal management.

Turning to the knowledge and skills needed to be successful in 21st Century electronics, Dr. Krishnan pointed out that companies like TI have re-invented themselves several times over the decades; we should be confident in our ability to do so again. The success factors are discipline, focus on bottom line, and calculated strategic actions. Successful employees must thrive in dynamic roles. They cross-train and are continually developing new core competencies. Successful employees focus on execution, and the best ones over-deliver. They are good at collaboration. New hires with graduate degrees must provide compelling value to TI. The need a broad understanding (design, test, process, statistics, coding, simulation, thermal properties, mechanical properties, …) and should have in-depth knowledge in selected areas. In addition to technical skills, demonstrated leadership ability and an understanding of organizational behavior are needed.

Dr. Krishnan emphasized the importance of soft skills such as taking initiative, having a sense of urgency, dealing with ambiguity, perseverance, driving for success, understanding manager expectations, embracing feedback, etc.

Dr. Krishnan ended with some advice for students. Excel at fundamentals (depth and breadth), be a good "citizen" of the organization, take responsibility for your work, and realize that companies have high expectations for new MS and PhD. graduates – they must provide compelling value.

**Dr. Geoffrey Coram: Analog Devices, Inc.**
Analog Devices Inc. (ADI) manufactures A/D and D/A converters, amplifiers, MEMS devices, power management circuits, etc. Dr. Coram stressed the increasing importance of sensors (for Internet of Things, self-driving cars, …). He pointed out that the real world is analog and that low power is critical for remote sensors and IoT. To address the opportunities of the 21st Century, ADI is increasing its emphasis on systems and on a high level of integration.

In thinking about the knowledge and skills needed to succeed in a company like ADI, Dr. Coram pointed out that students looking for careers in industry should not be too narrowly focused, and that we should recognize that this requirement is in conflict with what is needed to complete a successful Ph.D. The ability to learn is a critical success factor for the fast pace of industry today. Echoing the sentiments of other attendees from industry, he pointed out that an ideal candidate would have a solid background and an ability to learn, but to be successful in industry, communication is key. In dealing with customers, it is important to understand what the customer really needs – to see beyond the current request and truly understand the customer's problem.

Dr. Coram concluded by posing a question. Group projects help students develop their communication skills, but are their other ways that we can help students become excellent communicators?

**Dr. Colin McAndrew: NXP/Qualcomm**

Reflecting on 21st Century electronics, Dr. McAndrew pointed out that the semiconductor industry has matured. Today, things are system-driven, and circuits are commodity building blocks. Besides cost, key drivers are power, security, 5G, and system in package integration. Today, state-of-the-art CMOS is a commodity technology that companies like NXP obtain from foundries, but NXP continues to develop differentiating technologies.

Dr. McAndrew spoke about how to succeed in business by being a "technology driver". Technologies change rapidly; core knowledge does not. Dr. McAndrew has worked for five different companies and has been involved in several projects that failed and many that succeeded. During the course of this wide variety of work, he developed into an expert on compact modeling and statistical design, which were not the subject of his Ph.D. thesis. His key message was: "Don't strive to adapt to rapidly changing technology landscapes; highly successful engineers drive technology changes.

The ideal candidate for companies like NXP/Qualcomm would have deep core knowledge in science, math, numerical analysis, etc. Technology changes rapidly, but these fundamentals don't. Engineers use their deep knowledge of fundamentals to keep up with rapidly changing technologies. Depth and breadth are essential – it's important to understand what happens up- and down-stream of your own work. Good communication and collaboration skills are essential. New engineers should first look for ways to improve things, and then drive technology changes. They should learn to work collaboratively because it's both effective and enjoyable. Building networks in the technical community beyond your company is an investment in your future. In addition to enjoying a satisfying career, those who combine these soft skills with core technical competencies will do well financially too.

Dr. McAndrew's message was that jobs and job functions are certain to change; the best success strategy is to drive change rather than just striving to adapt. "Be a driver not a passenger."

**Dr. Mark Stettler: Intel**

Intel is a leader in pushing CMOS technology to its limits. Dr. Stettler directs Technology Computer Aided Design (TCAD) at Intel and spoke about the challenges of TCAD, the opportunities for students, and the technical and soft skills needed to excel at computational engineering in industry.

The simulation and modeling of modern CMOS technology is a multi-scale/multi-disciplinary challenge. Atomistic physics affects the properties of materials and devices, especially device variability. Materials and devices present challenges (depending on the problem, electrons must be treated classically or quantum mechanically, and both charge and spin are important), but at the die level, circuit performance, yield, reliability, and packaging considerations must be comprehended. The complexity of modern CMOS processes presents enormous challenges. The technical skills needed include atomistic physics, computational materials and chemistry, as well as imaging, computational geometry, compact modeling (of reliability too), and high-performance computing.

Positions in TCAD require a graduate education, which gives a person depth and shows that they are highly motivated. Doing thesis research is good practice on solving tough, ill-defined problems. A strong foundation in core classes as evidenced by good grades is needed. Students should have understood their thesis research – i.e. have owned their research and not merely followed the advisor's directions. Students aiming for a career in CAD tool development need C/C++

programming skills that are much stronger than those that the typical graduate student acquires. (Dr. Lee Smith of Synopsys emphasized the importance of programming expertise for careers in software development for electronics.)

Good communication skills are essential because individuals do not develop complex technologies. An important part of the job interview is to determine how well a candidate communicates, especially to non-experts, and how well they respond to questions. Developing these skills takes time and practice.

The top three challenges working engineers face in reverse order are: 3) staying technically current, 2) communicating effectively to influence bigger decisions, and 1) maintaining passion for the job. Successful people work hard after getting their degree, because they are passionate about their work. So find a job that you can be enthusiastic about, and probe the job culture before you join to be sure that it's a good fit.

Dr. Stettler identified some things that should not change about graduate education. The first is emphasis on the fundamentals that will sustain a career – don't short change fundamentals for current "hot topics." The second is thesis research. The specific topic is less important than the opportunity to learn how to solve complex problems at the forefront of technology.

Dr. Stettler also suggested some changes to consider: 1) convince more (and more diverse) students to attend grad school, 2) Pay more attention to software skills, which are waning, 3) give students more help on developing their communication skills, and 4) provide students with better career mentoring.

**Dr. David Yeh: Semiconductor Research Corporation**
Dr. Yeh did something rare – he spoke without PowerPoint slides! He spoke about going outside of one's comfort zone to expand knowledge and capability, and used the opportunity to demonstrate by speaking without the aid of slides. He hoped his remarks were an example to the students. Dr. Yeh also spoke about the big problems that we as a society face and the key role that electronics will play in addressing many of these challenges. He spoke about the importance of depth and breadth in addressing these challenges and urged students to think about how their research fits into the bigger picture of the big challenges what we as a society must address.

**Dr. Arun Malhotra: Western Digital**
Western Digital's business is storage with products for notebook/desktop computers to data centers. A 50,000X cost reduction in NAND memory price over the past two decades has driven growth. 3D memory architectures as well as increasing the bit density of individual memory cells will help continue this trend.

Dr. Malhotra identified four categories of skills that engineers in companies like Western Digital need: 1) Basic technical knowledge, 2) Advanced technical knowledge, 3) Infrastructure knowledge, and 4) Critical thinking skills. Category 1) could also be called Fundamental knowledge and includes topics like physics, chemistry, thermodynamics, solid state, materials science, mathematics, statistics, basic programming, electronics, and computer architectures. It also included devices, fabrication processes, packaging, and mechanical strength. Category 2) included advanced knowledge beyond the core fundamentals, as well as knowledge of currently important technologies and methods. Examples included advanced statistical analysis, new programming skills (e.g. Python), ReRAM, MRAM, PCRAM, 3D/multilevel Flash, vertical Integration, new materials, as well as big data, data analytics, and machine learning. Knowledge of recent advances in semiconductor fabrication, and in logic technology and nano-devices were also included. Topics like this must be learned on the job or in thesis research. Category 3) included several soft skills such as communication, understanding where HW and SW meet, appreciating different cultures and understanding how to work in teams and in multi-disciplinary environments. Also included in this category was an understanding of fundamental concepts in IP licensing (to patents, trade secrets and open source) that is fast becoming a big part of the business function of a corporation. Category 4) including understanding uncertainties in data, being open minded, taking risks, leveraging from different fields, and being a lifelong learner.

**Dr. Julio Costa: Qorvo**

Qorvo designs, manufactures, and supplies radio-frequency systems for wireless and broadband communications. Some of the older participants may remember RF Microdevices and Triquent, the two companies that joined to form Qorvo. The company's products address the exponentially Increasing data consumption of wireless devices. Data is now measured in EB (exabytes, $10^{18}$ bytes). Over the past decade, the number of frequency bands used in a phone has grown from 2 to more than 40 today. Today's RF front end modules are 8 layer laminates with multi band SiGe power amps, complex RFSOI switches and surface and bulk acoustic filters all in a 7.8 $mm^2$ footprint. Advanced packaging technologies and System in Package (SiP) technologies are increasingly important. Companies like Qorvo are relying more and more on external foundries to do custom technology development. Dramatically fewer positions are now available in process engineering.

Engineers in Qorvo need the kinds of soft and people skills other speakers discussed. Oorvo looks for engineers with a solid foundation in engineering disciplines, specifically:

- Solid State Device technologies
- Circuit Design with emphasis in Analog / RF Power / Low Noise
- Simulation Tools: Analog / RF / EM
- RF and Electromagnetic Theory and Practice
- Advanced Packaging Technologies
- Acoustic Filter Theory (SAW / FBAR / BAW)
- Communications System Architecture

New hires should be acquainted with simulation tools, but high-level training in the use of EM tools is done by the company. Hard to find skills, such as acoustic filter theory, must be picked up on the job. Head count is closely monitored. Echoing the sentiments of the speaker from TI, new hires must bring "extreme value."

## Appendix 2: Student Discussion and Survey on Graduate Education in Electronics

A summary of the student-led discussion of the survey results appears below. The complete survey results can be found at: https://nanohub.org/groups/needs/grad_ed_forum_2017.

***Q2: The best way to make electronics technology attractive to a new generation of students is:***

Students, faculty, and industry were in agreement that focusing on the role of electronics in addressing important societal challenges and in making "cool" products are the best ways to capture the interest of students. It was interesting that the industry group was the only one that thought focusing on fundamental science could play an important role.

***Q3: How long does a Ph.D. take (in years from a BS)?***
All three groups estimated 5-6 years, but students had the longest estimate and industry the shortest.

This question generated quite of lot of discussion about Ph.D. programs. One student expressed a desire for more hands-on courses. Others pointed out the disparity in the number of required courses (with Purdue being at the high end). One student felt that the undergraduate program is about fundamentals, and that the graduate program is not about taking classes – it is about gaining depth while solving a problem. A participant from industry talked about how as a graduate student, he had been opposed to taking classes, but he now realizes how valuable they were and still uses what he learned in graduate classes. There was some discussion about whether the Ph.D. is too narrow (a point made by Dr. Coram of ADI earlier). Opinions were divided, but several recognized real value in going deep into a problem and learning how to solve such complicated, ill-defined problems at the cutting edge. There was a comment from a student that Ph.D. programs should give students a better understanding of how their work connects to industry, but David Yeh, of SRC expressed the opinion that universities and industry are already well connected. Perhaps the issue here is that students supported by SRC have opportunities to connect to industry that other students may not have.

One interpretation of this discussion is as follows. Coursework provides broad and enduring depth in fundamentals. Thesis research develops deep expertise in a topic and may lead directly to the first job, but more importantly, it provides an opportunity to develop problem-solving skills.

***Q4: How long should a Ph.D. take?***
All agreed that it should take less time. Faculty, feel that it should take a little less, and students feel that it should take a lot less (1 year less). Because summers are the most productive in terms of research, the easiest way to shorten the time would be to eliminate student internships (which are not always aligned with thesis research), but these were generally felt to be good experiences.

**Q5: How should graduate program balance technical depth vs. technical breadth?**
All groups felt that technical depth should be the highest priority, but that there should be some breadth as well. Colleagues from industry agreed on the need for depth, but valued breadth much more than faculty.

***Q6: Graduate program should include training in soft skills.***
All agreed that this would be useful, but about one-half worried about the impact on technical training. A significant fraction (more than 1/3) felt that these skills are so important that they should be included even if technical training suffers. One international student pointed out that practicing these skills also provides students with opportunities to learn about U.S. culture. The challenges that non-native English speakers have in developing good English communications skills were also discussed, but a faculty member pointed out that native English speakers also struggle with good technical communication. A representative from industry pointed out that faculty often do the communicating for students, and this limits the practice that students get. One student mentioned that numerous resources and opportunities are available for motivated students to practice their soft skills. Perhaps the issue is students who are not aware of the importance of these skills and of the resources available and busy faculty who focus on helping students get publications and shortchange the development of students' soft skills. How do we make sure that development of the soft skills of students doesn't fall through the cracks?

***Q7: Internships in industry are useful.***
There was general agreement on the question. The strongest support came from industry, and the next strongest from students. One student, who did an internship every year of his Ph.D. spoke about how useful they are. In his case, the topics were perfectly aligned with his thesis research, so the internships accelerated his path to the Ph.D. The internships also gave him an opportunity to see a variety of companies and make an informed decision about which one to join. There was some discussion about whether the best time for an internship is early in the Ph.D. or later. Doing one early allows the student to focus on the thesis research later, but the student might not yet be mature enough to make a good impression on the company. Doing it later may distract from finishing the thesis. In the ideal case, an internship project is a part of the thesis research. A significant fraction of faculty did not feel that internships are useful. The fact that internships often slow down research may be the reason.

***Q8: Ph.D. programs require major changes meet the needs of industry today.***
Overall, about 40% agree and about 25% are not sure. Faculty expressed the strongest support for the need to change.

***Q9: More emphasis on MS programs is needed.***
Opinions were divided on this question, and unfortunately, there was no time for discussion about masters programs.

***Q10: The most important quality needed to be successful in industry is:***
Problem-solving skills was the clear winner with communication skills a strong second. Breadth of knowledge had some support, but deep expertise was not identified as a key success skill.

***Q11: The most important quality needed to be successful in academia is:***
All agreed that deep expertize is the most important, but faculty and students also rated communications and breadth of knowledge as important skill for academia.

***Q12: How do you use online educational resources?***
Everyone uses theses resources for introductions to new topics. Students also use them for learning software skills.

***Q13: What software skills are essential?***
Proficiency in programming, data analysis, simulation, and large-scale computing were all mentioned. Data analysis was important to all, but twice as important to the industry group. Simulation and large-scale computing was important to faculty and students, but not to colleagues in industry.

***Q14: Proficiency in what programming language is essential for engineers today?***
Faculty and students had a strong preference for MATLAB, but there was little preference for MATLAB was expressed by industry. Industry expressed a strong preference for Python, but Python was almost absent in the student responses. The strongest preference for C/C++ came from industry. A representative from industry pointed out that the rigor and structure of languages like C/C++ is necessary for those who will do significant software development.

***Q15: The most exciting areas to work in these days are:***
Energy, healthcare, and robotics were mentioned frequently.

***Q16: Ten years from now, do you expect to be working in solid-state electronics?***
Most said yes or maybe.

***Q17: The most interesting career opportunities today are in what fields?***
Students rate system companies, semiconductor companies, and academic highly. A non-trivial number of students is not sure.

**Q18: I am generally aware of broad trends in electronics**
Most feel that they are aware or strongly aware of broad trends. About 15% of faculty are not sure, about 22% of students aren't sure, but only 6% from industry aren't sure.

**Q19: I learn about technology trends by:**
Attending conferences, reading journals and magazines, and discussions with colleagues were the most common means identified.

**Q20: How can the diversity of people in electronics be increased**
Suggestions included setting metrics, learning from disciplines that are more successful than we are, more outreach to young students before high school, and more role models.

***Q21: What general suggestions for improving graduate education to you have?***

- Focus on the right balance between 1) technical depth vs. breadth, 2) Trending technologies vs. fundamental technologies, and 3) Soft vs. technical skills.
- Strengthen connection with industry.
- Emphasize ethics and don't neglect liberal education
- Provide more flexibility in coursework, especially at the master's level.
- Take full advantage of on-line educational resources.