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Statistical Engineering—Roles for Statisticians and the Path Forward

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INTRODUCTION

Statistical engineering (SE) is a term that has been around in the statistical literature for more than 60 years. Over the years, it has been defined and used by a number of different groups and organizations to encompass a variety of different but sometimes related concepts. Here we focus on the definition proposed by Hoerl and Snee (2010a), which uses the definition of engineering as "the study of how to best utilize scientific and mathematical principles for the benefit of mankind" (p. 52). In other words, this definition considers how existing (and sometimes new) statistical tools can be combined and applied to solve important problems.

In Part 2 of this panel discussion, we ask questions of our panel of prominent experts from diverse areas of industry, government, and academia about the changing roles for statisticians in the SE workplace and discuss some of the opportunities and challenges for the future. In this second article we consider:

6. Emerging roles for statisticians with SE.
7. How universities can get involved with speeding the development of new statisticians.
8. Key first steps to establishing SE as a field.
9. Potential pitfalls in the development of SE.
10. How national statistics organizations can help.
11. How individual statisticians can get involved.

After the panelists present their thoughts and insights on the six questions, the editors highlight some of the key points from the discussion. Again, for those new to SE, these highlights may be a good starting point to give some frame of reference, before returning to the more detailed comments from the panelists.

ROLE FOR STATISTICIANS

Question 6. As we work in this new area, where are opportunities for statisticians to define new roles for themselves within their companies and work places?

DeHart and Van Mullekom

As we think about the role of statisticians in industry, we are reminded of Peter Block's discussion of Schein's three consultant roles—pair of hands, expert, and collaborative (Block 2000). The table below summarizes these roles and gives an example in a statistical context.

Role	Pair of hands	Expert	Collaborative
Description	The consultant plays a passive role and merely applies his or her knowledge as outlined by the client	The consultant is assigned to solve an immediate problem and given the freedom to make decisions based on his or her technical expertise	The consultant and clients work interdependently. As such, the consultant is able to help clients sustainably solve problems
Example	A client may provide the statistician with a data set and request that a two-sample *t*-test be run to compare the company's newest product versus the best competitive offering	Given the task to prove that the company's newest product is superior to the competition, the statistician determines which data to collect and how, and selects the most appropriate analysis technique to complete the comparison	The statistician may work with the team to develop a general process for comparing the company's products to competitors' products that includes information technology (IT), integrated data collection, analysis, and delivery of results
Key issues	The consultant may use the wrong analysis tool or solve the wrong problem because he or she lacks full knowledge of the project	Solutions may not be adopted or sustained because the consultant may be viewed as an outsider and the business may not feel any sense of ownership	Working collaboratively is resource intensive and is not appropriate for every business problem or project. Collaborative work must be carefully selected

We agree with Block's (2000) statement that though the collaborative role is ideal, it is not always appropriate or feasible. There are situations where acting as a pair of hands or expert is sufficient and more suitable. In fact, we would argue that applied statisticians often find themselves working as a pair of hands or an expert and do so very successfully. However, today's society also needs statisticians to work in the collaborative role to help solve the most important problems. SE supports and encourages this collaborative role for statisticians to help them become more essential members of interdisciplinary teams and integrate statistical thinking throughout the corporation. It allows statisticians to become the "go-to" person for the creation of credible data based decision-making tools.

Leadership opportunities also exist in the form of thought leadership and project leadership (Hoerl and Snee 2010b). For example, as a thought leader, statisticians can suggest ways of making use of the company's existing or future data in a repeatable format that can change the direction of business. This also changes the role of the statistician from a reactive support person to a proactive solution provider. In many organizations, statisticians are already viewed this way. However, for the isolated statistician or for those groups that have not been able to make these strides, SE can be the springboard for the transformation.

Jones

Statisticians have become unpopular in some environments by adopting the role of gate-keeper versus collaborator. Such statisticians view their role as passing judgment on every proposed design or data analysis project. This attitude impedes work rather than accelerating it.

A new role for statisticians is as active participants in projects helping engineers make data-driven decisions despite resource and time constraints.

There is also a role here for computational statisticians. Much statistical software implements statistical methods as named tools or functions. This puts the onus on the user of the software to know the

appropriate tool and its correct application. The challenge for the next generation of statistical software is to flatten the learning curve for nonexperts and to provide more contextually sensitive methods.

Vining

SE properly applied gives statisticians greater opportunities to participate as core contributors, as colleagues, rather than as consultants. Core contributors are involved from the very beginning of projects. Their colleagues view their perspectives and participation as vital and an inherent element to the project's success. Typically, project teams use consultants only as needed for specific problems. Consultants are not viewed as essential; rather, they are viewed as overhead. In too many cases, consultant selection goes to the low bidder. In today's global climate, a consultant whose only contribution is data analysis competes with statisticians worldwide who may work for a much lower wage. The future of industrial statisticians in North America and Europe lies in becoming full colleagues with the subject-matter experts. SE is a good strategy for achieving such a goal.

Wilson

A critical distinction for statisticians is defining themselves as *collaborators* instead of *consultants*. The distinction here is between a statistician who is an integrated team member versus a statistician who is consulted to address specific questions or issues. SE, which envisions substantive, high-value application of statistical tools and thinking, will not be possible to implement without having statisticians embedded in the problems and processes they are addressing.

Hoerl and Snee

We believe that SE provides opportunities for statisticians to develop their own career paths in unique ways. For example, because SE provides approaches to attack large, complex, unstructured problems, statisticians have the opportunity to demonstrate more leadership in addressing these "mission critical" problems, rather than only providing passive consulting services on narrow technical questions. Such work can lead to even broader roles, such as project leadership. SE also requires more interdisciplinary collaboration, enabling statisticians to expand their impact and influence.

In short, statisticians who can effectively apply statistical thinking at the strategic level, and SE at the tactical level, in addition to their skills using the tools, will have more job and role opportunities in their careers than statisticians who are only good at data analysis. We believe that this concept is consistent with published models of career development, such as Dalton et al. (1977).

Parker

There are certainly new, exciting, and challenging opportunities for statisticians through SE. SE promotes the idea of statisticians embracing collaborative leadership roles in solving large complex problems. By definition, these types of problems have higher visibility within the organization and therefore present the opportunity for statisticians to be recognized for their contributions. From my experience, if you are seen as a problem solver or a go-to person within your organization you will be recognized and rewarded. Alternatively, if you are simply seen as someone who possesses some specialized skills or tools, your impact and recognition is limited because those skills and tools may be found elsewhere or outsourced. As statisticians, we certainly possess high-powered tools and, most important, an ability to recognize the impact of uncertainty in decision making. However, we should strive to be known for the problems we have solved, rather than the tools used to solve them.

Clark

For statisticians to obtain new roles in their companies, they need to express their contribution to corporate management in a more meaningful manner than reducing variation. A study (http://www.leansigmatalent.com/2010_study_results) by The Avery Point Group, a global executive search firm, suggests that the demand for statisticians in Lean Six Sigma (LSS) is declining. They examined almost 3,500 recent Internet job postings. The 2010 study showed that Lean talent demand exceeded Six Sigma (SS) talent demand by almost 35%. Also, for those companies seeking Lean talent, only 41% require

candidates to possess SS knowledge as well. The Avery Point Group associated SS knowledge with a heavy emphasis on statistics and variation reduction. Previous surveys had shown SS talent as being more desirable than Lean talent.

One opportunity is for statistics to assume a broader role in LSS. We can use statistical methods and tools to reduce waste. That is, SE could remove waste. For example, an LSS project could use simulation to identify waste—for example, long waiting times—and predict the benefits of reducing waste.

This perception that the benefits of statistics are totally expressed by reducing variation is partially self-inflicted. In January 1994, the Statistics Division (Britz et al. 1996) adopted a tactical plan to enable broad application of statistical thinking. The American Society for Quality's (ASQ) Statistics Division definition of statistical thinking follows. Statistical thinking is a philosophy of learning and action based on the following fundamental principles:

- All work occurs in a system of interconnected processes.
- Variation exists in all processes.
- Understanding and reducing variation are keys to success.

Britz et al. (1996) assigned Deming's theory of profound knowledge as the original source of the Statistics Division's definition of statistical thinking. Variation has a broader scope than one might suspect. Britz et al. (2000) listed four types of variation. They are

- Off-target
- Common cause
- Special cause
- Structural

Structural variation occurs when causes occur in a predictable manner. For example, the waiting line for a table at a restaurant might be longer on Saturday evenings than on other days. Off-target variation occurs when the process average does not meet the organization's desired target. Thus, reducing variation includes improving averages.

The variation types listed above suggest that statistical thinking is a philosophy of learning and action to improve key process output variables (KPOVs). If that is our meaning for reducing variation, we need to

- Emphasize and promote this broader meaning for statistical thinking.
- Develop SE methods and tools for implementing statistical thinking.

With this broader meaning for statistical thinking, individuals capable of implementing statistical thinking and SE would be employed in Lean aspects of LSS. Also, if the primary purpose is to improve KPOVs rather than reducing variation, statistical thinking appears more as a business or organizational improvement philosophy rather than as a more limited quality improvement philosophy.

Montgomery

One possibility is to find ways to participate in both formal and informal groups within the organization. For example, there may be periodic company-wide engineering or technology meetings. These could be opportunities to give presentations and network to attract new collaborators.

Simpson

We need more capable, aggressive, engaged statisticians willing to work side by side with engineers and scientists who need solutions to tough problems. More statisticians need to not only score successes in SE projects but also market their value to the organization and lead the creation of new positions. As the chief operations analyst for the Air Force, Dr. Jacqueline Henningsen once told us, "The best jobs are the ones you create" (personal communication).

SE should also not restrict practice to only statisticians. Consider broadening the list of discipline practitioners to include specialists formally trained in operations research, decision sciences, operations management, industrial engineers, and systems engineers with a strong background in statistics. In fact, an SE group would be more productive if designed as an interdisciplinary team able to more readily comprehend complex systems and more easily establish credibility.

Question 7. Most statisticians graduate with little formal training in the synthesis of different tools—it is something that

good applied statisticians have largely learned for themselves as they collaborated with colleagues in other disciplines. What can academic statistics departments do to help accelerate students on their path toward developing and mastering these skills?

Clark

The statistics departments should add subject matter in two areas to its required courses. The first area will cover the methodologies and tools used in statistical engineering. This area would include LSS methodology and tools, among others. Topics such as cause and effect diagrams, QFD charts, and value stream mapping would be included. After learning the methodology and tools, the second area would consist of participating in real process improvement projects. The students would form teams, and the instructor would find project sponsors in the local area. In many universities, the Industrial Engineering Department already has courses in these two areas. The Integrated Systems Engineering Department at The Ohio State University does. One option is for the statistics department to require these courses as part of its degree requirements.

Hoerl and Snee

Several things would help: First of all, there should be formal course work in synthesizing tools. Meng (2009) discussed one such "problem-solving" course at Harvard. Some universities such as Virginia Tech, North Carolina State, and Arizona State provide training in structured problem solving, like Six Sigma, which has integration, linking, and sequencing of tools at the center of the methodology.

Secondly, courses on specific methodologies, such as design of experiments (DOE) or regression, should teach these not as sets of isolated tools but rather as sequential approaches that work better when deployed from a process point of view, rather than via one-shot studies. For example, in the DuPont strategy of experimentation approach, students are taught to first identify the critical variables using screening designs and then identify good operating areas using characterization designs, such as full factorials, and then search for optimum regions with response surface designs. This approach provides students with a general strategy for attacking design problems versus simply having a large number of tools in the tool kit but not knowing how to go about using them in an integrated fashion.

We would further argue that university statistics programs should consider the option of dissertations in SE, in addition to statistical science. Such dissertations would emphasize development of the theory of SE—how and why methods should be linked and sequenced, as opposed to just development of new methods.

MacKay and Steiner

We have written elsewhere (Steiner and MacKay 2009) about a course on our version of SE that we teach to senior undergraduate and graduate students at the University of Waterloo. The course uses a virtual environment called Watfactory (see http://sas.uwaterloo.ca/Faculty/VirtualProcess.shtml) that allows students to practice SE in a realistic term-long simulation. Throughout the course as they work through the SE algorithm, student teams conduct a series of empirical investigations and make oral and written reports documenting their progress and the logic underlying their tactics. The students are generally enthusiastic about the course. Here is a quote from a student letter to our Dean about Steiner's recent offering: "Of all the classes I've taken over the past 4.5 years (48 as of today, 52 at time of graduation), STAT 435 is the one that has taught me the most. The course's strengths lie in its real-world applicability, and its multi-faceted approach to finding solutions to problems" (2006).

We strongly recommend such a course as a capstone. STAT 435 focuses on the tactics and thought processes needed to work through the SE algorithm. We introduce no new formal analysis tools and emphasize graphical and numerical methods for decision making.

Wilson

Statistics departments could learn from their engineering colleagues and consider developing a capstone design course that lasts one or two semesters. Descriptions of these courses typically include working with a local company to identify a project idea;

working through the project with a small team; developing project proposals, progress reports, and presentations; designing software and computations; writing a final integrated report; and presenting a final report to the client and the department faculty. This would be an intensive course for statistics department faculty to develop because it requires identifying local clients with problems that could benefit from a synthesis of statistical tools and methods.

Another critical element is the integration of more statistical computing into statistics curricula. SE is not a "paper-and-pencil" enterprise; it requires the development and implementation of IT solutions. Statisticians will likely not build the IT solutions, but they must be familiar with the fundamentals of computational reasoning and the practice of computing with data. See, for example, Nolan and Temple Lang (2010) for ideas on how to integrate more (and different) computing ideas into statistics curricula.

This question assumes that training for SE will occur within departments of statistics. However, that might not necessarily be the case. Few statistics departments are housed within schools of engineering. Would SE be more easily housed within an industrial engineering department or as an independent department? When teaching engineers statistics, I have found that the students were completely comfortable with mathematics as a tool. An alternate way to think about the goal of training in SE is to train engineers to have similar fluency in statistics. This will not be accomplished simply by adding a statistics class to current engineering curricula but will require a new model for introducing statistics as a tool and integrating it throughout training.

Montgomery

Statistics departments could emulate engineering programs. All engineering programs must have a senior design course (either one or two semesters in length) that requires team-based integration of the tools of the discipline to solve a real design problem. In addition, engineering students also have to take a specific number of academic hours in courses that have demonstrated design content. These are Accreditation Board for Engineering and Technology (ABET) accreditation requirements. The senior design course is often a project in local business or industry, supervised by faculty, and involving people from the project sponsor. Engineering faculty involved in the design course invest in making contacts with local business and industry to ensure that project opportunities are available. Statistics departments could incorporate a design-like experience into their undergraduate or M.S. programs. They could also seek to collaborate with engineering departments and have statistics students participate on engineering student design teams. The learning experience for engineering students from senior design is invaluable. A similar experience could be very useful for statistics students.

Simpson

The dilemma facing statistics graduates is the same as in most science disciplines. Business schools have learned from the Harvard program and often teach tools and methods courses via case studies. They present students with vague, unstructured problems that require students to learn how to formulate proper objectives and then determine the situation-specific solutions. Another accessible opportunity to gain practical experience would be to require participation in the engineering schools capstone team-based senior design projects.

One final suggestion is for the department to establish a collaborative relationship with industry partners—a win–win situation for the students, faculty, and industries. The mechanism could be in the form of a center of excellence with a mission for applied research and collaborative opportunities, with internships and a pipeline for postgraduation hiring. Several schools, including Virginia Tech, have successfully built such a center.

Parker

Statistics departments can articulate and promote a broader role for the statistician in practice and the faculty can model this role in their research and consulting. There should be an expectation within the statistics departments to produce more well-rounded graduates with an understanding of fundamental business processes and organizational structures. There should also be an emphasis on leadership skills and communication. To clarify my suggestion on communication, I am not only referring to the efficient solicitation of subject matter knowledge to

frame the statistical solution approach but also teaming with other disciplines and communicating the basic ideas of statistical thinking to nonstatisticians. In addition, being able to communicate results to nonstatisticians and focus on the impact rather than the mathematical beauty of the methods used to achieve those results. Multidisciplinary training in other subject matter fields has been promoted for some time within our profession and is essential to SE for quick team integration.

For students to seek these additional skills, there must be faculty role models. This may be the most challenging aspect of better preparing statisticians for the role of SE. In most statistics departments, promotion and tenure metrics do not reward the practice of SE but rather promote methodological research. However, the ability to bring in research funds should provide a motivation, as in many engineering departments. This is clearly where SE fits better as an engineering discipline rather than a statistical discipline. Faculty members who have developed collaborative roles with industry and government should leverage those successes and fund graduate student internships focused on SE. In particular, these faculty members should be actively, collaboratively defining the high-impact problems to be solved. They should be strategic and organizational leadership facilitators and model those aspects to the student interns.

Vining

A good starting place is to give unstructured, somewhat complex problems as class projects in the standard courses. Such class projects represent only a start given the time limitations of a one semester course. It also is important to note that not every instructor is comfortable introducing unstructured, complex problems successfully. Such problems require real subject matter expertise in order to guide students through the process. Even when the instructor has appropriate subject matter expertise, students often are unfamiliar and uncomfortable with unstructured problems. Such students find the solution of well-defined problems more self-contained and less intimidating. They do not understand the need to deal with unstructured more complex problems.

Another possibility is to modify the standard consulting course. One major problem here may be that people think that SE is nothing more than consulting. These people might do little or nothing to change the consulting course to reflect the realities of large, unstructured, complex problems. Instead, the instructor may continue to emphasize how to interact with clients (merely a specific tool within SE). The course will continue to have subject-matter experts, almost always from on campus, provide a greatly oversimplified problem that the instructor expects the class to solve by the end of the period. Students will come out of such classes no better prepared to deal with large unstructured complex problems than they do now.

The next logical step is to encourage more internships and graduate research assistantships where the students work on real complex, unstructured problems outside of academia. Such internships and assistantships require well-experienced mentors from both the sponsoring organization and the university. This step is the best one currently available to most graduate curricula. Students get the best experience and appreciation of SE within a realistic context.

The most critical thing that academia can do is to develop true SE courses above and beyond the basic introductory course. Such course development requires serious buy-in from academic administrators and national granting agencies.

DeHart and Van Mullekom

Statistics departments can provide many opportunities to accelerate students on the path toward developing and mastering these skills by altering their course work requirements, cultivating internship programs, and providing interactions with practicing applied statisticians. Course work should include case study classes where "the answer is not in the back of the book." Using business or law schools as a model, these courses would include real-world problems in their business context. Students would be required to solve these problems and develop the appropriate tools and reporting to make them operational. Discussions and debates of alternative solutions in the classroom as well as a presentation of the actual business solution developed would be important.

Internships expose students to a variety of real-world problems; however, exposure to the problems is just one aspect of the experience. The real value comes in watching the experienced

statistician ask the business questions, develop the statistical approach, and deliver the solution. Over time, the student can internalize this process of SE until it becomes intuitive. Statistics departments should follow the example of universities such as Texas A&M, UC Davis, the University of Delaware, the University of Pittsburgh, and Virginia Tech by offering credits toward graduation requirements for those students who complete an internship.

Interactions with practicing statisticians can be valuable at several levels. Student interactions with real-life statisticians in the form of colloquia and short courses can also be a vehicle to provide exposure to complex problems and their statistically engineered solutions. These interactions must provide an opportunity for dialogue to gain a true understanding of the nature of business and the reason a particular solution was applied. On the other hand, faculty interactions can focus on developing SE theory. Members of academia and industry can work together to document case studies and justification for their use of specific tools and methods. Faculty should be encouraged to take sabbaticals in business and vice versa. This faculty/employee trade, "stat-swap," could provide opportunities to develop powerful solutions and needed theory to instruct future statisticians.

Strong action is critical to creating successful statisticians in business and industry regardless of the future of SE. We encourage statistics departments to work with industry to implement these changes.

PATH FORWARD

Question 8. What are some key first steps to getting SE up and running? Where are resources needed to help accelerate the process?

DeHart and Van Mullekom

In order to develop the statistical engineering discipline, industry and academia must work together. Both sides need to devote resources to collaboratively build its foundation. Real industrial case studies need to be documented and the structure and theory need to be defined and validated. Journal articles and textbooks need to be written and courses need to be designed.

So who can do all of this? Academics can refocus their research to SE theory, but they cannot do it alone. Industrial statisticians must also participate. In addition to providing real examples of SE, industrial statisticians can also assist with curriculum development and even instruction. Universities can hire retired industrial statisticians in faculty roles. Current industrial statisticians could also be hired as adjunct faculty members. Universities and corporations could even participate in a stat-swap where faculty members and employees trade jobs for a few months. However, universities must find a way to make such positions attractive to current industrial statisticians, who work very busy schedules and receive attractive salaries. Some statisticians may view this work as a service to the statistical community and take a proactive role, whereas others may need a little more incentive. The American Statistical Association (ASA) must consider the relative weight of such activities in the evaluation of candidates for ASA Fellow.

Hoerl and Snee

We believe that academic research would accelerate the development of SE more than anything else. This would help establish the underlying theory of SE and help illustrate how theoretical development in SE is different from theoretical development in statistical science.

At the same time, practitioners need to be identifying large, unstructured complex problems; creating effective solutions; and communicating their experiences and results to the profession so that we can build and enhance the body of knowledge. We also need professional societies within ASA and ASQ to embrace SE as a viable topic for major initiatives, papers, and conference sessions.

Simpson

The most important first steps are to establish a sense of urgency (that the organization must infuse SE or suffer consequences) and work with and within organizations to deliver short-term wins. In addition, SE, as a new discipline, often requires culture change in the way an organizational conducts business. Change will not be effective or lasting without someone to lead the effort, to infuse statistical thinking in all product and process development.

For the short-term wins, organizations, leaders, and projects need to be identified where there is either an effective team already in place or an environment where this change is welcome. One such environment is the Department of Defense operational test organizations. Statistical thinking is required by the oversight agency, so many test organizations are only beginning to develop a SE capability but welcome the support. So willing stakeholders and leaders of a couple of varieties—leaders in statistics to build it up from the ground floor to grow project wins, along with leaders to champion the cause and turn engineers from obstacles to collaborators—are essential ingredients for success. Ultimately, we cannot place enough importance on the organizational executives who believe in the value of SE and are committed to affecting the change. Dr. Mike Gilmore, the director of operational test and evaluation, is one such example. He not only provided the policy but his action officers are enforcing it, and he is actively sharing the message and story.

Parker

The growth of SE requires culture change, both from the perspective of how statisticians view their role and how other organizational elements (e.g., leadership and subject-matter experts) view statisticians. Statisticians need to be seen as valued added collaborators, and active in solving high-impact problems. From my experience, a crucial element is building a collection of examples. I intentionally used the word *examples* rather than *success stories* because we can motivate the ideas of SE from both successful and unsuccessful examples. To be clear, there certainly needs to be successful applications; however, critical illustrations of how a project could have been better executed by using SE are extremely helpful. In addition, I think we need to be very careful to not oversell SE as the latest solution to all of our organizations problems, because this will likely lead to underdelivering. We need to manage expectations and be clear about the limitations of SE.

Within an organization, once there is a credible body of work to illustrate the process of SE, then we need to work with leadership to inextricably link SE to the ability to achieve organizational objectives. We are all familiar with the saying that the three most important features that determine value in real estate are location, location, and location. For SE to grow in practice and impact, I believe that the three most important elements are leadership, leadership, and leadership. This applies at multiple levels and within different spheres of influence.

Montgomery

Statistics and industrial engineering departments should begin a dialogue. Between the two departments they likely have the courses and faculty, so it should not be too difficult to design good minors or certificate programs of the type I have previously described. Then, publicizing the program, attracting students, and interesting employers have to be started. Companies that have strong SS initiatives and a track record of doing SE should be approached about considering these students in their hiring plans and considering funding some research projects.

Vining

The proper resources on the academic side would be a $8,000,000-a-year commitment by an National Science Foundation (NSF) director to support statistical engineering research and course development: $2,000,000 per year for a national center of SE, $3,000,000 per year for true interuniversity research projects (two new grants per year each for $500,000 a year with 3-year commitments), and $3,000,000 (four new individual PI grants each for $250,000 a year with 3-year commitments).

On a more realistic note, good first steps include the following:

- Several tracks on SE at multiple U.S./international conferences.
- A major dedicated conference, preferably sponsored by several major corporations.
- Getting editors at the major industrial statistics journals to promote the basic ideas within their journals.

Some of these activities are well underway as we speak.

Jones

Key to success in my view are as follows:

1. Development of the details of the core content of SE.
2. Pull from business and industry.

4. Academic programs that provide students with a credible grasp of the core content.

Getting industry partners will be difficult without a more fleshed-out description of the content and the potential benefits. I would point to the Institute for Advanced Analytics at NC State as a model.

Question 9. Though the path forward is filled with potential and the end goal holds great promise, where do you anticipate potential pitfalls in the development of SE?

Jones

Right now Roger Hoerl, Ron Snee, and a small community are strong voices pushing for a change. Push marketing is an uphill struggle. When there is pull from the market, product flies off the shelves. Business and industrial leaders need to see the potential benefits of SE and promote it. SE needs what Jack Welch did for Six Sigma.

I believe that if SE does not succeed in making a case for the discipline in academia, it will suffer the same fate as the various quality initiative and management fads of the last several decades.

There must be substantial core content to be mastered. And SE must provide demonstrations that the application of this core content can yield a substantial improvement over current practice.

Vining

The "theory" underlying statistical engineering is learning how to take a large, unstructured, complex problem and then (1) break it into manageable pieces, (2) understand the underlying structure for each piece, (3) perform the appropriate analysis, and (4) bring all the pieces together. Right now, there is a different theory for most problems. The hard part is determining the commonality across these problems and synthesizing an appropriate theory.

Another pitfall is that many academics will confuse SE for what many statisticians consider statistical consulting. SE is not a preservation of the profession's status quo, although many current statisticians will try to repackage it to preserve and to justify what they currently do. I already have seen this phenomena take place at conferences that have presented basic ideas of SE.

Montgomery

Academic programs will not flourish unless there are jobs for the graduates (so getting recognition from business and industry that these graduates have valuable skills that they really need is key), and there also needs to be meaningful research opportunities for the faculty. And, at least in engineering, this means research that can attract external funding. There currently are not many sources of funding for the kinds of research that supports SE. If industry really needs the students, they may need to step up to the research funding plate to support the academic programs and faculty who produce the students that they hire. This has happened in bioengineering, where there is a lot of industry and private foundation funding.

MacKay and Steiner

The statistical establishment is highly resistant to change. We suspect that this is the greatest potential pitfall. We love teaching our current tools and developing new ones, context free and with no guidance for application such as that provided by SE. As one small example of our reluctance to change, we include a tactical framework to the design and execution of any empirical study within our version of SE. We call this framework question–plan–data–analysis–conclusion (QPDAC). See MacKay and Oldford (2000) or Steiner and MacKay (2005) for details of the guidance provided within each step.

Outside of SE, we introduced this framework into our beginning statistics course at Waterloo, but other instructors found it very difficult to teach and assess partly because marking non-mathematical questions was seen as too onerous. We were unable to convince our immediate colleagues of the advantages of a tactical approach. After some years the course was again redesigned to virtually eliminate the QPDAC material. Sadly, we are pessimistic about selling a more complex set of tactics and principles to the statistical community that controls the education of future statisticians.

Even with Six Sigma training/books aimed mostly at practitioners there appears to be a tendency to focus predominantly on the tools. Little time/space is spent exploring the connections between the different stages of design–measure–analyze–improve–control (DMAIC). Examples used in one portion of books are often not discussed elsewhere.

Wilson

The canonical example cited by Hoerl and Snee (2010a), the development of Lean Six Sigma, points to one potential pitfall. LSS is a framework that is applied across multiple business models, and developing LSS required the engagement of an entire disciplinary community over many years. Though this is an SE success story, it will not be typical of the work of a single statistical engineer developing "statistical engineering solutions." In order to attract students and practitioners, it will be critical to develop smaller, focused case studies that can be used as illustrations and taught as examples.

DeHart and Van Mullekom

We do anticipate a few pitfalls in the development of the statistical subdiscipline of statistical engineering. First, the name itself could prove to be problematic. In fact, we have participated in several debates with other professionals around the label of SE. Everyone agrees that statisticians should have a high degree of participation in the activities characterized by SE; however, some are hesitant to adopt the term. Many may question the difference between SE and applied statistics upon hearing the term for the first time. On the other hand, some may confuse this area with applying engineering to statistics. Even furthermore, some engineers are offended by the extension of their career label to a new area. An effective communication plan that characterizes SE is essential.

Another potential problem is that some may view SE as merely a marketing gimmick or the "flavor of the month." To combat this attitude, a solid case that illustrates the need, benefits, and sustainability of SE is needed. Industry must clearly see the true value that SE brings. Documenting and sharing of real industrial problems with excellent SE solutions that benefit mankind and corporations' bottom lines can support this case.

Gaining alignment with statistical group managers and business leadership is another key aspect to furthering the discipline of SE. Corporate initiatives such as SS flourish because of their top-down deployment. Though SE does not require a corporate deployment, it does require champions driving these efforts as a result of a business need. Grassroots efforts will result in spotty success and inconsistent application to tough business problems. Statisticians must consider their influence strategy to build advocates within their organizations. Again, this may be happening in some corporations but others may need to generate support for the concept.

This leads us to another challenge: publishing case studies in leading journals. Industrial statisticians must take the time to publish their work to broader audiences, and journals must provide industrial statisticians with an avenue for sharing. Journals must recognize the need for case study articles and devote a portion of their issues to such papers. We propose a journal created especially for this purpose entitled the *Journal on Statistical Practice* in conjunction with the ASA Conference on Statistical Practice.

Hoerl and Snee

A major potential pitfall would be if a large portion of the profession felt that SE was something relevant for business and industry, but not relevant for academia, pharmaceutical development, or government. Unfortunately, we believe that to some degree this is what happened within the statistics profession with Deming's message and the "quality revolution." Though there are certainly many positive counterexamples, all too often Deming's message about statisticians improving all aspects of society was interpreted as a message only relevant for industry. This was not so for the quality profession, but we feel it was for the statistics profession. Another potential pitfall is if the underlying theory of SE becomes dominated by successful case studies, rather than by true research. Case studies are important, of course, and they can illustrate theory. A successful case study in itself does not determine theory, however.

Parker

A primary motivation of SE is to broaden the impact of statistical thinking and methods in solving significant socioeconomic problems. When we lose sight of our overarching goal, the potential pitfalls will consume our energy and slow our progress. I think we are always at risk of spending too much energy on distinguishing SE from classical applied statistics, which is often done with the goal to make

SE more palatable to those who consider themselves as applied statisticians already practicing SE. Similarly, too much effort on convincing academicians that we are not denigrating the need for statistical research may not be productive. Discussion is good, and it sharpens our ability to articulate the definition and motivation of SE; however, motivation by fear of disenfranchising certain groups needs to be carefully considered. I suggest that we focus on the work to be done to make SE a viable, recognizable, long-lasting discipline.

Question 10. How can statistical organizations (such as the American Statistical Association, the Statistics Division of the American Society for Quality, and the Quality, Statistics and Reliability Section of Institute for Operations Research and the Management Sciences [INFORMS]) help the growth and dissemination of SE?

Hoerl and Snee

As noted previously, the first step is for them to recognize SE as a discipline. Next, they can begin sponsoring conference sessions, not to mention whole conferences devoted to SE. They can also ensure that there is an appropriate representation of SE in their journals and newsletters. Often, submissions to publications are based on the empirical data set of previous publications. This makes it difficult for a new topic such as SE to break in. Having special publications devoted to SE can help address this problem and hopefully lead to a good mix of statistical science and SE submissions in the future.

Parker

Clearly, facilitating a discussion through publication and conferences is the central role of these organizations. Though all of these organizations can play a role, I wonder if they want to play a role? Do these organizations recognize SE as a benefit to the statistical profession and the future of statistics, or are they watching on the sidelines to see if it fails to gain momentum? We should acknowledge that it is very difficult to overcome naysayers and old paradigms within these organizations. In my opinion, the discussion needs to be focused on the recognition of a problem to be solved within our profession and an effort to clearly articulate the motivation and potential benefits of SE, rather than sliding into petty disputes over terminology.

Furthermore, SE venues should seek to broaden the participants and link members from existing professional societies. For example, the 2011 NASA Statistical Engineering Symposium strategically created a forum for interaction among organizational and technical leadership, engineering and science subject-matter experts, and statisticians, because collaboration among these entities will advance the SE discipline and maximize its benefits. The meeting featured exchanges that are usually not available, because these participants would not have attended each other's professional meetings. Meetings of this nature will be more effective if we include both the benefactors and the practitioners of SE. Our efforts to make this a team sport and include the beneficiaries as partners and collaborators may do much more to promote the growth of SE than our efforts within statistical societies.

Professional training through these societies will help practicing statisticians, but there should be a strong focus on academic training to prepare new graduate for the expanded role of SE. As an aspiring engineering discipline, we should engage ABET and begin to develop a SE curriculum.

DeHart and Van Mullekom

Statistical organizations can help the growth and dissemination of statistical engineering in a variety of ways. The journals associated with each organization can dedicate sections of each issue or even a special edition to SE case studies or research. The ASQ is doing just that with this special issue of *Quality Engineering*. These organizations can also devote conference sessions to the topic, in particular invited sessions or keynote addresses. The ASA has gone even a step further than that by organizing the first Conference on Statistical Practice held in February 2012. This ASA conference is focused on bringing together industrial and academic statisticians in order to improving statisticians' abilities to solve real-world problems. Another key way that statistical organizations can contribute to the growth of SE is by providing the necessary financial resources for research and collaboration. These

organizations may offer grants themselves; moreover, they can also influence larger grant funding organizations such as the National Science Foundation. Engagement of other scientific disciplines and societies such American Institute of Chemical Engineers (AIChE), American Society of Mechanical Engineers (AMSE), etc., is another potential area for the growth and dissemination of SE. Also, publishing SE case studies in nonstatistical trade publications can create the business pull necessary to drive the discipline.

Wilson

Statistical organizations can most easily facilitate sharing knowledge. They can assist statistical engineering by providing visibility at meetings (for example, roundtables at the Joint Statistical Meetings and sessions at conferences); by identifying and publicizing which journals would be amenable to SE publications (and perhaps ultimately sponsoring a peer-reviewed journal); and by sponsoring SE workshops.

Vining/Montgomery/Jones/Simpson

The ASA Section on Quality and Productivity (which appears sympathetic), the ASA Section on Physical and Engineering Statistics, the ASQ Statistics Division (which is very sympathetic), the ASQ Chemical Process Industries Division, particularly through the Fall Technical Conference, and the INFORMS Quality, Statistics, and Reliability Section must embrace the concept and ensure that sessions, preferably tracks exist at their conferences on the topic. The Institute of Industrial Engineers, the European Network for Business and Industrial Statistics (ENBIS), and the Institute of Electrical and Electronics Engineers (IEEE) Reliability Society are other organizations that should be involved. Networking opportunities and professional conferences to showcase cases and examples would help build a community and accelerate the learning across different applications.

Journals and journal editors can also help by sponsoring special issues focused on SE and encouraging expository articles and relevant case studies. ASA and ASQ could sponsor a journal of SE for the purpose of providing examples of good methodology and promoting the discipline.

Question 11. What suggestions do you have for individual statisticians as to how they can get involved to

a. Develop their knowledge of statistical engineering?
b. Solve large, unstructured problems with high impact on the organization that employs them?
c. Contribute to the development of statistical engineering as a discipline?

Montgomery

Get involved with the people in your organization who do engineering, science, and business analytics. Try to avoid the consultant role and make an effort to be recognized as a full team member and participant from the beginning of projects. Building a network both inside and outside your organization can help. One of the most valuable aspects of professional society membership and involvement includes going to conferences such as the ones mentioned in Question 10 as networking opportunities.

Jones

If you are in business or industry, think about the role you are playing now. Are you a gate-keeper or a facilitator? If you are not a part of any team that has direct responsibility for adding economic value, search for any opportunity to get involved in a supportive role.

If you are in a university, try to convince yourself that your research and teaching are beneficial to society. If you are not satisfied with your answer, you may find that SE is worthy of your time and energy.

MacKay and Steiner

We believe that to develop SE further, large numbers of individual statisticians need to practice a current version such as Lean Six Sigma. This requires getting out into the field and observing how SE works (and how it fails). The lessons learned through practice are difficult to acquire in any other way. In our experience, it is difficult to arrange for established statisticians to work in the field. Few of us

want to get dirty hands, but there are potentially great benefits for all when we do.

DeHart and Van Mullekom

It is important to note that not everyone needs to be a statistical engineer. The field of statistics still needs theoretical and applied statisticians. Furthermore, statistical engineering is aligned with certain work style preferences and personality types. A statistical engineer must be a team player and also a leader. A statistical engineer must also have the creative ability to translate existing statistical methods to new applications. If this still sounds like the job for you, then here are some thoughts as to how you can contribute.

Most important—be a leader. Be assertive and take a proactive role in your career and in SE as a discipline. We encourage all statisticians to publish journal articles and present papers at conferences. Additionally, statisticians can become more active at their alma mater or at a local university by speaking during colloquia or even serving as an adjunct faculty member. Statisticians can also disseminate the ideas of statistical and systems thinking by sharing their experiences with other organizations within their own companies and mentoring fellow statisticians. Lastly, statisticians must never stop learning. Statistical engineers should not only continue to improve their statistical abilities but also devote time to improving softer skills such as leadership and communication.

Parker

I suggest that statisticians seeking more knowledge of SE need to proactively find examples in written articles, conference presentations, and direct communications with those who practice SE. I specifically modified that suggestion with the term *proactively*, because at this time it will take effort and commitment to find these edifying examples. This special edition of *Quality Engineering* will start to fill a gap in the literature regarding SE. As the body of knowledge regarding SE increases, it should become easier to find resources, but for now it will take perseverance and active participation. In addition, I encourage publishing your own examples of applying SE and contributing to the SE conversation.

In terms of solving large, unstructured problems with high impact, my advice is twofold. First, be disciplined within your organization to identify problems with high impact, not just those you perceive to have high impact. Seek to collaborate with organizational leadership to obtain buy-in on the problems you set out to solve. Second, with confidence and resolve, systematically attack these problems with an attitude to not work harder but rather smarter. Assemble a multidisciplinary team, clearly define your objectives, and manage stakeholder expectations. A particular strength of a statistician is that we are generalists who can apply statistical thinking and methods to a broad variety of problems and have incredible impact. For large, complex problems we need to rely on collaborative efforts as a team. A simple test you can apply to determine whether your problem is large and complex is whether you can solve it by yourself. If you can solve it by yourself without teaming and collaboration, then the problem may not be large enough to have significant impact.

Hoerl and Snee

We encourage readers to read existing publications to develop their knowledge of SE and then write their own! The literature on SE so far is very limited, especially on underlying theory. We need more publications and case studies showing how to integrate various methods together into overall approaches to improvement. Readers should also consciously look for opportunities to apply SE in their own environments. We suspect that people can learn most quickly about SE by applying it themselves.

Experience with using SE will be gained in the process of solving large, unstructured problems with high impact. People must be consciously looking for SE opportunities. In many organizations it is safer to focus on narrow technical problems that we know how to solve—problems that do not require SE. We would encourage statisticians to look for the big, complex, unstructured problems in the organization and then attack them with SE approaches. This is a riskier proposition, because success is not guaranteed. In most cases, doing so will require statisticians to exert leadership and initiative. Rarely will the problems come to them; in most cases, they will

need to find such problems. One way to identify critical problems is to talk to leaders of organizations, asking them what they see as critical problems the organization must deal with now or in the future. What critical business issues "keep them up at night"?

One strategy to make this happen is to position yourself to take advantage of the opportunities when they are identified through your efforts or that of others. Providing leadership and delivering timely and useful results on the projects you work on enhance your reputation as an effective leader and contributor. Such a reputation increases the probability that you will be asked to get involved when high-impact, mission-critical projects are identified.

To contribute to the development of SE as a discipline requires us to first talk about it! Whatever statisticians talk about when getting together at conferences or in their workplaces becomes part of the discipline. We would encourage statisticians to attend SE sessions at conferences and get involved in the dialogue. Consider submitting SE publications to appropriate journals. Case studies are certainly needed. This all helps to enhance the SE body of knowledge and build the discipline.

Simpson

To develop your knowledge: Get involved, team with mentors, do not be afraid to fail, understand that the problem drives the tools.

To gain exposure to large unstructured problems: Volunteer, create openings, get out of the office, listen to colleagues, offer assistance, start small to learn, gain self-confidence, and build the trust of the client.

Vining

Today's individual statisticians need to learn how to think "outside the normal box" in terms of what they do. They need to seek broader experiences and the opportunity to work on large unstructured complex problems. When they attend conferences, they need to talk with people who have successfully tackled such problems. Finally, current industrial statisticians need to engage in the debate and conversation on SE and its ramifications.

EDITORS' DISCUSSION AND CONCLUSIONS

First, we would again like to thank all of the panelists for their contributions to the discussion of the evolving role of the statistician and the future of SE. To help the reader synthesize the discussion, we summarize some of the key points. We have listed the panelist(s) associated with the ideas within the discussion of each question. For related ideas from other questions, the author and specific question numbers are listed. For questions Q1–5, see the first panel paper (Anderson-Cook et al. 2012).

Question 6

In the first of the two questions that consider the role of the statistician in the SE paradigm, we see that there are clearly some opportunities for statisticians to redefine how we are perceived, where we make contributions, and our position in our organizations. The framing of the different roles of consultants (DeHart & Van Mullekom) gives more precise definition to the desired collaborative role for SE statisticians (Wilson, Vining, Simpson, Parker). With a focus on the big picture of business, statisticians can emerge as integrators and disseminators of statistical thinking (Clark, DeHart & Van Mullekom). This will lead to leadership opportunities for statisticians, both as thought and project leaders (Hoerl & Snee, DeHart & Van Mullekom), who can champion data-driven decisions (Jones, Hoerl & Snee, Simpson, Q1, Parker, Q1).

Another prominent theme is the aim to move from reactive support people to proactive solution providers (DeHart & Van Mullekom), who are capable, aggressive, and engaged in formal and informal interdisciplinary teams (Montgomery) to solve hard problems (Simpson). Statisticians should actively participate as core contributors (Vining, DeHart & Van Mullekom, Parker, Simpson) who work on important problems to organizations and are central to business success (Hoerl & Snee, Parker) and should strive to be seen as problem solvers and go-to people (Parker) who accelerate progress rather than gate-keepers who hinder advancement (Jones). By defining our role more broadly than just those who work on variance reduction (Clark), statisticians

should work to improve key process output variables (Clark) and be known not for the tools we use, but for the problems we solve (Parker).

Finally, statisticians can strive to have impact not only on solving problems but also disseminating results, marketing their value to the organization, which could lead to the creation of new positions (Simpson). This can be effectively achieved through expressing our contributions in meaningful terms to the organization (Clark). Statisticians who can successfully accomplish these will have more job and career opportunities (Hoerl & Snee).

Question 7

There are a number of ways that universities can help new statisticians to develop the needed skills for the emerging SE roles. Within the curriculum, existing courses should include discussion of sequential problems solving using multiple tools (Hoerl & Snee, DeHart & Van Mullekom), focus on connecting work to the business impact (Clark), and formally discuss synthesizing tools (Hoerl & Snee, Wilson). Incorporating case studies (Simpson) and increasing exposure to real applications (DeHart & Van Mullekom, Clark, Vining, Steiner & MacKay) will add relevance to standard statistical tool discussions.

New courses should be developed (Vining) to focus on fundamental understanding of business processes and organization structures (Parker), tools that focus on problem diagnosis (Clark), problem-solving tactics and thought processes, and facilitating decision making (Steiner & MacKay), as well as communication and leadership skills (Parker). Methods should also be included for decomposing large unstructured problems into manageable pieces (Vining, Simpson) and encouraging decision making based on the collection and analysis of data (Steiner & MacKay). A capstone course in statistics programs (Wilson, Steiner & MacKay, Montgomery) or participating as a team member in an engineering capstone course (Simpson) would provide a more in-depth experience with improving a real process from its initial problem definition through delivery of the final solution.

For more in-depth experiences, students and faculty should collaborate with industry through internships and graduate research assistantships (Simpson, Parker, Vining, DeHart & Van Mullekom), and academia should value and reward funds generated through these interactions (Parker). A center of excellence (Simpson) could coordinate these collaborations, and faculty should be encouraged to serve as role models for students as leaders in the broad practice of problem solving (Parker). Statistics departments could encourage dissertations in SE (Hoerl & Snee) on the development of theory, formal tactics, and approaches for solving large, unstructured problems with a suite of statistics and other tools.

Two other key areas of training include developing solid statistical computing skills (Wilson, Jones, Q6) and gaining expertise in other specific disciplines (Parker) by participating in multidisciplinary training. Courses designed to bring students with both statistics and engineering expertise together to work on problem solving (Wilson) could be highly beneficial.

Question 8

To establish SE as a new discipline there are a number of key initial steps and areas where resources are needed. Involvement and support from both academia and industry are essential to success (Jones, DeHart & Van Mullekom), with academia contributing underlying theory (Hoerl & Snee, DeHart & Van Mullekom) and active research through business–academia and interdepartmental collaborations (Montgomery) and industry contributing examples, case studies, and demonstrated best practices (Hoerl & Snee, DeHart & Van Mullekom, Parker), and participating in training and curriculum development and even instruction (DeHart & Van Mullekom). The collection of examples should include successful and unsuccessful projects and demonstrate both the strengths and limitations of the approach, as we guard against overselling SE as a magic bullet for all problems (Parker). The early stages of industry and academia collaboration should focus on the development of the core content of SE (Jones).

Culture change will also be a key factor in the success of SE development. Change is needed both in how statisticians view their roles as well as how others view contributions made by statisticians (Parker). With urgency and purpose, we need to demonstrate short-term wins leveraging from already

established teams in conductive environments to influence how organizations conduct business (Simpson). By securing leadership support and commitment (Parker, Simpson), demand or pull (Jones) for the benefits of SE from business and industry can be generated.

Publicity and dissemination of SE-related activities and research should be fostered through journal articles (such as this collection in the special issue), conferences, and conferences sessions (Vining, Hoerl & Snee). Additional publicity efforts should be directed toward attracting strong students into the area (Montgomery) and developing career paths for students of SE (Montgomery). These qualified students available for employment (Jones) will be ambassadors of the success of SE. In addition, funding from granting agencies and from industry to support the development of the underlying theory and training program (Montgomery, Vining) as well as creative programs such as stat-swap (DeHart & Van Mullekom) can help build momentum.

Question 9

Realistically there are numerous obstacles and challenges ahead on the path toward developing SE as a discipline. Most important, the effort could falter if there is not broad buy-in from both the statistics and nonstatistics communities (Jones, DeHart & Van Mullekom, Q5) in both academia and industry (Hoerl & Snee). This engagement and participation is required through a long-term sustained commitment (Wilson). Creating pull from business and industry leadership (Jones) will require successful and strategic marketing of the merits of SE (DeHart & Van Mullekom) and demonstrated success stories. There also needs to be an alignment of statistics group managers with business leader to cooperate toward success (DeHart & Van Mullekom). In broadening the potential impact of SE, it would also be highly advantageous to consider applications beyond business and tackle difficult socioeconomic problems (Parker).

Branding SE will also have challenges. The name statistical engineering has an established history with alternative definitions (DeHart & Van Mullekom). For people to connect with this current initiative, the foundations of SE need to be well defined and easily articulated. We need to demonstrate that SE is better than what is currently available (Jones, DeHart & Van Mullekom), as well as distinguish it from statistical consulting (Vining, Q7 and Q9) and the latest fad (DeHart & Van Mullekom). A collection of real problems with excellent solutions (DeHart & Van Mullekom) should help to consolidate advances, and smaller and more focused case studies should be helpful for training and illustration purposes (Wilson).

At universities, a case needs to be made of the advantages of SE, for faculty rewards, funding and acceptance (Jones, Montgomery, Hoerl & Snee), as well as for students to have a well-defined and promising career path (Montgomery). Venues for publication are necessary for faculty to embrace this as a viable area of research (DeHart & Van Mullekom). Developing the underlying theory (Vining, Hoerl & Snee) across a breadth of applications will depend on being able to find commonalities in large, complex, unstructured problems (Vining) and formalize key elements and patterns for success.

Reluctance to change and move away from the comfort of the status quo can hinder progress (Steiner & MacKay). If those teaching the next generation of statisticians do not embrace a definition of statistics to include problem-solving tactics beyond tools and methods (Steiner & MacKay), then an opportunity to accelerate the development of SE may be lost.

Question 10

Support from national and international statistics organizations can help with some aspects of the development of SE. Virtually all of the panelists are in agreement that statistical and nonstatistical journals, special issues (such as this one), conference sessions, and SE-themed conferences present core opportunities for dissemination and education on SE. Statistics organizations can help publicize these outlets (Wilson) and help educate journal editors about the importance and potential impact of SE. Once editors are more aware of SE, then they can encourage submissions in this area (Vining, Montgomery, Jones, Simpson). Including newsletter items and information on Web pages about SE can also increase awareness in the broader community (Hoerl & Snee). In addition, organizations can sponsor training (Parker), workshops (Wilson),

and networking opportunities for discussion and education (Vining, Montgomery, Jones, Simpson) in conjunction with conferences or as separate activities. This support will help formalize their recognition of SE as an emerging discipline (Hoerl & Snee).

The leaders and members of national and international statistics organizations can also play important roles in accelerating the development of the SE body of knowledge (Parker) and engage ABET in the process (Parker). Organizations approaching the key funding agencies and encouraging them to embrace SE will help spawn active research and buy-in from academia (DeHart & Van Mullekom). By engaging other disciplines and societies to help them understand the broad benefits of SE for solving large, unstructured problems (DeHart & Van Mullekom), the discussion can be broadened to include more participants, including those who will benefit from the improvements of the SE problem solving (Parker). Finally, organizations can help discussions and debates focus on the important issues and try to prevent the conversation about SE from degrading to smaller details and distractions (Parker).

Question 11

Individual statisticians have an important role to play, both to develop skills for their own benefit professionally as well as to help SE grow and mature. Though SE may not be required for all problem-solving situations or an ideal fit for all statisticians (DeHart & Van Mullekom), we feel that some exposure and appreciation for its importance to business success would be highly beneficial for all. The panelists offer diverse suggestions that should be helpful for individual statisticians to select from based on their own situations and interests.

It is an important challenge for all statisticians to consider how they add value: In industry by facilitating and not hindering progress as a gate-keeper and in academia by working on problems of real benefit (Jones). Reaching out to other disciplines (Montgomery) and interacting with them directly to solve important problems (Parker, Simpson) will lead to opportunities to participate in real applications (Steiner & MacKay, Hoerl & Snee, Simpson, Vining) as part of interdisciplinary teams (Parker). Working on real applications will help reinforce that problems drive tools (Simpson).

Getting started requires education: read background material, existing case studies, and articles in this special issue and attend conference sessions to improve core understanding (Parker, Hoerl & Snee). Continue to learn and develop statistical and nonstatistical tools and skills (DeHart & Van Mullekom) and connect with mentors or experienced statisticians to help guide your development (Vining, Simpson). In the early stages of developing SE acumen, it is helpful to start with smaller problems. This will help to learn, develop confidence, and build the trust of your collaborators (Simpson).

It is important to become involved in improvement projects early in their defining stages to help establish participation as a full team member and avoid the consulting role (Montgomery). Taking on a leadership role in teams (DeHart & Van Mullekom, Hoerl & Snee) can guide data-driven decision making throughout the improvement process and allow opportunities to collaborate with organizational leadership (Parker) to focus on high-impact problems (Hoerl & Snee, Vining, Parker). In general, being proactive in seeking opportunities for participation (DeHart & Van Mullekom, Parker, Hoerl & Snee) will open doors and create new prospects.

To help SE develop as a discipline, network and share experiences (Montgomery) and engage in the conversation and debate on SE (Parker, Vining). Join professional societies and become one of the leaders helping to shape the evolution of SE (Montgomery). To help populate the literature of SE, contribute case studies or papers on the topic (Hoerl & Snee, Parker). As a community, we can leverage from each other's experiences and expand our body of knowledge.

We, the editors, would again like to thank the panelists for their thoughtful and thought-provoking contributions and ideas. We hope that you will agree that SE offers many new roles and opportunities for statisticians, and we encourage you to become involved as we progress toward developing SE as a formal area within statistics.

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