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Effective interdisciplinary collaboration between statisticians and other subject matter experts

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\section*{ABSTRACT}
Progress and innovative solutions to challenging problems often come at the intersection of multiple disciplines. Statisticians frequently are presented with opportunities to participate on or lead interdisciplinary teams, where how well their contributions are received is a function of their effectiveness as collaborators. In this article, we outline six fundamentals for effective collaboration: respect, shared common goals, trust, commitment, intercommunication, and execution. We focus on how these core aspects of a successful collaboration can be encouraged by statisticians. Through an example, we illustrate how problems can arise when some of the key components are missing and what strategies can be used to mitigate problems. Finally, we describe how early career statisticians can work to improve their collaboration skills to improve their impact on teams with diverse backgrounds.

\section*{KEYWORDS}
Statistical engineering; interdisciplinary collaboration; team; decision-making; problem-solving

\section*{Introduction}

As you navigate through the rest of your life, be open to collaboration. Other people and other people’s ideas are often better than your own. Find a group of people who challenge and inspire you, spend a lot of time with them, and it will change your life. \textit{Amy Poehler}

Modern innovation, creative solutions, and advancement of science and engineering are often achieved through interdisciplinary collaborations that leverage the intersection of expertise between team member disciplines (Olson, Parayitam, and Bao 2007). By the nature of expertise spread across multiple research and subject matter areas, teams are often diverse in their backgrounds and approaches to synthesizing information and problem-solving are needed. Cognitive diversity can be defined as differences in perspective or information processing styles (Reynolds and Lewis 2017). Indeed, there is a growing literature that demonstrates that cognitively diverse teams have the potential to outperform those with more homogeneous backgrounds. Cognitively diverse teams have been shown to solve problems faster (Reynolds and Lewis 2017), be more innovative (Denning 2012; Viki 2016), and generate higher quality solutions (Hong and Page 2004). In addition, top companies are beginning to recognize the opportunity of intentionally formulating diverse teams for competitive advantage (Seiter 2015). Since many challenging problems involve the need for data collection, analysis, and combining subject matter-specific knowledge with data, there are important roles for statisticians to play in collaborative research and problem-solving (Anderson-Cook 2009). Also, there is great potential for statisticians to use data-driven tools and methods to help bridge the gaps between multiple disciplines and cognitive diversity to offer more structure to the discussion and decision-making process for reaching team decisions that are supported by all team members. If the discipline of statistics is going to continue to thrive, we think that it is vital that statisticians can make substantial contributions in solving high-consequence problems. As noted in Hockman and Jensen (2016), science stands to benefit when statisticians play a leadership role in innovation.

In this article, we discuss some of the fundamentals of interdisciplinary collaboration and how statisticians with their unique perspectives and expertise in statistical thinking and statistical engineering can be a catalyst in collaboration. We appreciate that there are many other types of collaboration, including mentor-mentee (Anderson-Cook et al. 2017) and statisticians
collaborating with each other, but our focus for this article is on the specific challenges and opportunities for statisticians on interdisciplinary teams. The importance of the message is highlighted by the fact that even if you possess a mastery of powerful statistical tools, you may never get to open your toolbox and influence a high impact project without being included on an interdisciplinary team and being able to effectively collaborate. Without the ability to collaborate, the specialized knowledge of several subject matter experts may not be integrated across disciplines to solve the right problem or answer the right question. On the other hand, having an effectively collaborating team can accelerate the problem-solving process and is more likely to come up with better solutions. Covey (2011) talks about the 3rd alternative – the option of not your way or my way – as the way to seek an elevated solution that is better than the sum of the parts on a team. This is the goal of collaboration: to find a solution that takes the best and most relevant expertise of the group and turns it into new best practice. In addition, Covey talks about how the by-products of a deeper understanding of others and a strong commitment to the solution result from the process of careful and considerate collaboration.

The advantages of being an interdisciplinary team member span several different categories: for the individual statistician collaborator, for the team, for the organization, and for the broader discipline of statistics. For the individual statistician, the opportunities include improved job satisfaction through their contributions in solving high impact problems. Many applied statisticians were drawn to the discipline because of the opportunity to make a difference and solve meaningful problems. Teams with diverse expertise and knowledge often consider larger, more complex high consequence problems. Contributing as part of these teams allows statisticians to have a more substantial impact and to consider more interesting and challenging problems. This enhances the impacts of statisticians’ work and success in these roles can lead to opportunities for career advancement.

For the interdisciplinary team, including a statistician who is able to collaborate effectively as part of the team can lead to advantages as well. With an understanding of statistical thinking (Hoerl and Snee 2012), statisticians can encourage the team to think deeply about the role of variability and uncertainty on the system and incorporate these ideas into the solution and its assessment. Including ideas of statistical engineering (Anderson-Cook et al. 2012a, 2012b; Hoerl and Snee 2010), multiple statistical tools, and methods can be incorporated into the problem-solving process to integrate data-based decisions throughout team discussions. Biases from incomplete information and ineffective group dynamics (Anderson-Cook 2017) can also be mitigated by focusing on data-centric, structured decision-making or problem-solving approaches (Anderson-Cook and Lu 2015). By providing graphical tools to visualize alternative options (Anderson-Cook and Lu 2018), statisticians can also help facilitate discussions to evaluate different choices on the path to a final solution. Opportunities for innovative solutions can also be increased as statisticians can challenge standard disciplinary practices for the current problem and facilitate better team understanding of relevant discipline knowledge (Jensen et al. 2012).

For the organization, there are opportunities for improved use of time and resources through more efficient data collection using designed experiments, tailored statistical analyses, and more justifiable decisions. In addition, the quality and relevance of solutions can be enhanced through the inclusion of statisticians on the problem-solving team. Including quantitative and evidence-based approaches to the organizational business culture can improve its productivity and competitiveness.

Finally, the perception of the statistics discipline can be elevated through demonstrated contributions to solving high impact problems. For decades, there has been a discussion about the perceived struggles of statistics to obtain adequate respect, relevance, and appreciation (Bross 1974; Pfeifer, Marquardt, and Snee 1988). Once statisticians are sought after for involvement in interdisciplinary teams by demonstrating their potential to contribute, these issues of acceptance resolve themselves. In addition, being involved in these complex important problems can provide opportunities to develop new leading-edge statistical methods. Incorporating statistical thinking and methods as an integrated part of scientific discovery enhances creativity and accelerates interdisciplinary innovation. Statisticians can play a unique role in utilizing the power of data to bridge gaps between diverse expertise and accelerate cross-disciplinary and transdisciplinary research leading to scientific discoveries.

Hence, the benefits of including statisticians on interdisciplinary teams are numerous, but are predicated on the effective contributions of statisticians to enhance team performance. The goal of the article is to adapt concrete strategies from the literature of other disciplines for statisticians to provide a roadmap for the reader to become a better collaborator. There are two aspects of the strategies that we outline for
This improvement: (1) the art of collaboration that evolves as a function of experience, mentoring, and observation; and 2. methodological research which forms the underpinning of the science of collaboration. While each individual has their own talents and potential to be a collaborator, we believe that all statisticians can improve and become better collaborators with the benefit of exposure to some fundamentals. In the section “Fundamentals of Effective Collaboration for Statisticians,” we discuss some of the fundamentals of effective collaboration from the perspective of the unique contributions that statisticians can bring to interdisciplinary teams. We have divided the fundamentals into categories and have sought to connect them to core principles documented in the behavioral science and industrial–organizational psychology literatures.

The six categories that we consider for successful interdisciplinary collaboration are as follows: respect, shared common goals, trust, commitment, intercommunication, and execution. Respect focuses on understanding the limitations of each team member while focusing on the strength and expertise that they bring to the collaboration. Shared common goals mean that all members of the team are focused on solving the problem, and in particular that statisticians are equally interested in the overall project goal, not only a restricted methodological view of the data collection or analysis. Trust centers on having a safe environment for frank discussion, the need for abiding by the agreed-upon process and having all the team members honor and defend the final decision outside the team. Commitment involves engagement throughout and striving to have the statistical contribution be integrated into all aspects of the decision-making process. Central to integrating the team and their expertise is effective communication between team members about the objectives and the technical aspects to achieve the goals. Intercommunication for statisticians begins with genuine curiosity to understand the contributions of each discipline and the ability to share statistical ideas and methodology in a way that all can understand. Finally, execution integrates the team’s plan with specific data collection and analysis strategies to achieve results. Also, the key to this category is ensuring that the gains achieved by the problem-solving process are implemented to enable the improvements to be entrenched for the future.

In the section “A Detailed Collaboration Example,” we provide some examples of our collaborations on teams that highlight some of the fundamentals discussed in section “Fundamentals of Effective Collaboration for Statisticians.” The section “How Should Statisticians Prepare” suggests strategies for how early career statisticians can prepare and develop their skill set to be ready to participate as effective members of an interdisciplinary team. Finally, the “Conclusion” section includes some discussion and conclusions.

### Fundamentals of effective collaboration for statisticians

The success of interdisciplinary collaborations hinges on a core set of fundamentals to building an effective functional team for achieving better team decisions and solutions.

### Respect

Interdisciplinary teams are formed by people from diverse backgrounds with different expertise. Respect offers an important starting point for the team members to acknowledge their differences, strengths, and weaknesses, and blind spots to work toward synergy and reaching consensus. Respect means accepting members’ different backgrounds and perspectives, understanding their strengths and weaknesses, and focusing on the positive aspects that each individual brings to the team. This fundamental understanding and acceptance can help build a safe environment for team members to worry less about revealing their limitations and the security of their own roles, but to focus more on seeking the best solutions to satisfy the team mission and achieving common goals. Since statisticians are not expected to have in-depth subject matter expertise for many applications, an opportunity exists for statisticians to ask leading questions about why certain aspects are important, how standard norms in different disciplines are relevant to the problem at hand. They can also request clarification of technical details to help form a solid common foundation of knowledge for the entire team. A common group-think problem that may occur during team decision-making is a common knowledge effect, which tends to overvalue the information shared by a majority of members on a team (Esser 1998). By openly discussing the fundamental knowledge from different disciplines needed for the decision, all members of the team will have a common set of information on which to base their assessments.

In addition to respecting individual team members, it also means mutual disciplinary respect. Engineers, physicists, economists, and statisticians should all be appreciated as having equally important expertise for
helping the team achieve better solutions. Historically, statisticians may not be considered as equally important as other subject matter experts on multidisciplinary teams. Pfeifer, Marquardt, and Snee (1988) state that “Our profession is plagued by lack of public understanding of just what we do and the contributions that we can make.” This was partially due to statisticians’ own mindset of viewing themselves as a supporter or peripheral to the decision-making, instead of a full and active team member. Many statisticians portray themselves as a consultant or a cooperating on the team project and simply offer statistical tools to help solve local problems, instead of contributing with opinions on the global question of interest. This has resulted in less involvement and respect for statisticians as equal contributors to the team skill set. Statisticians have to earn respect by having the appropriate perception of themselves and making active contributions toward the primary mission of the team to validate their relevance and importance. Indeed “we must think of ourselves as scientists who can make a difference” (Pfeifer, Marquardt, and Snee 1988).

Respect is also the foundation for having unfiltered, productive conflict around ideas. A team that respects each other’s roles and expertise is less likely to be afraid of healthy conflicts to investigate the heart of the issues that they face. They are more likely to engage in active debates around issues and solutions in order to leverage the potential of the cognitively diverse team to find better answers and make better decisions. Fear of conflicts or being judged by their colleagues often leads to self-censoring, which diminishes the team’s ability to effectively brainstorm solutions and evaluate the merits of alternatives.

**Shared common goals**

The second key aspect of a successful collaboration is to have shared common goals. Given how diverse modern interdisciplinary teams are, it is important to have a set of explicit goals for motivating, directing, and engaging their members. First of all, it is important for all members to have a clear picture of the mandate of the team and what success means at the end of a project. The goals need to be objective, specific, and quantifiable. Do they want to design and manufacture a new product with new features on components A, B, and C, or do they want to enhance the current production line by reducing the variability by 25 percent? The goals need a careful definition of the scope of the problem to solve with quantitative specific metrics to allow for assessment of progress toward the goals. The goals need to be clearly articulated and agreed upon by the team members so that those with different backgrounds do not have different views or distinct interpretations about what the team wants to achieve as a group. All members should be able to connect the team objectives to their own responsibilities and expertise. A useful strategy to check this is to have the team members explain their roles and contributions to their organizations at a nontechnical level understandable by others with different backgrounds.

Also, goals should be challenging and fine-tuned to motivate all members to work toward the common solution. They also need be substantive and important so members care about achieving the goals. In addition to setting clear goals, it is important for the team to invest time and efforts to ensure the maximum buy-in from the individual members. The success of the project can be compromised by having individual goals and agenda that are not matched well with the team goals. Having frank discussion of potential issues, concerns, and conflicts at the start of the project can mitigate problems and encourage all team members to embrace the goals. With shared common interests and clear views of their roles, team members will be more motivated and actively involved throughout the whole process. Each individual will participate as a full member with strong interests in achieving the ultimate goals, instead of focusing on just a portion of the project and making sure that their individual contribution is noticed. Historically, some statisticians have fallen into the trap of wanting their analysis to be noticed, instead of focusing on how to influence the overall decisions and solution. As the cognitive diversity literature has shown, engaged involvement of experts from diverse fields throughout the process can generate more innovative breakthroughs at the intersection of disciplines (Denning 2012).

**Trust**

The third critical element for building an effective and highly functional team is to build trust within the team. Trust is considered foundational at the base of Lencioni’s pyramid of highly functional teams (Lencioni 2011). Lack of trust encourages the team members to conceal their weaknesses and to be afraid of showing vulnerability or making mistakes. It also may discourage frank discussions as people are fearful of conflicts, prone to stay in their own comfort zones
and hesitate to offer help outside their own areas of responsibility. This creates boundaries between team members from different fields and substantially limits the team’s creativity and productivity. Alternately, members of a team with high levels of trust accept questions and suggestions about their areas of responsibility and also feel comfortable offering feedback and assistance outside their own domains. They can have unhindered discussions on issues important to the team’s objectives, are willing to challenge adequately justified choices, and appreciate constructive questions or feedback from others. This greatly improves the performance of the team by focusing time and energy on problem-solving rather than managing behaviors.

For a trusting team, once a decision is reached, it is honored and owned by all the team members, particularly when discussed outside of the team. All team members make sincere efforts to support and defend the team decision and making sure it is properly implemented to achieve the best possible outcome. Building a trusting team depends on the safe respectful environment and sharing a common objective. It takes time, all team member’s efforts and involvement, and active leadership to get there. However, without trust, the important foundation for building a strong and highly effective team is extremely difficult (Covey 2006).

Commitment

Built upon trust, the next key element to effective collaboration is to maintain a strong commitment to the team and the goals of the project. Commitment ensures that team decisions and the plan of action are followed through to deliver the desired results. It requires team members to hold one another accountable for their behaviors and performance. It demands a high standard of work and the quality of the solutions. Lack of commitment by one or more team members can result in deviations from the team’s objectives, decisions, and action plans, as well as unnecessary delays in progress. The current business environment demands timely results, so any delay in carrying out team action plans or inefficiencies in team decisions can result in missed deadlines and loss of opportunities.

Trust is essential for commitment to take hold, as it facilitates open discussions and the ability to challenge the team about important issues. It is human nature to stick to what we believe in, but a commitment to the team and the process may require adapting our views. For statisticians, there may be tension between the practical restrictions of what the team is able to do and what ideal statistical practice would demand. If statisticians are to be full team members, they need to be able to explain where this tension causes potential issues for achieving the team’s goals, as well as find creative solutions that allow for both aspects to coexist for a practical solution. If team members fail to follow agreed-upon decisions, then this may be a result of lack of clarity or buy-in. Therefore, members who have strong beliefs in some key factors to the team success should share their perceptions with the team so that all team members have empathy for each other’s positions while still working toward the overall goal. Shared common goals can generate shared attention to results, which encourages commitment to decisions.

For statisticians, committing to the team’s success means ensuring statistical thinking is integrated throughout the problem-solving process, statistical tools are properly used to analyze and deliver results, and realistic decisions are made based on appropriate quantification of uncertainty. It is also the job of statisticians to ensure the statistical contribution to the outcome is embraced by all the team members and statistical thinking is well understood for all aspects of the team’s endeavors.

Intercommunication

Intercommunication is key to fostering effective teamwork. When communication channels are properly established between team members, it creates a more comfortable and friendly environment for people to ask questions, clarify objectives, terminology or technical details, share information and insights, and report issues or complications in the execution of the action plans. Good communication also increases team members’ intimacy, reduces the possibility of misunderstanding, and helps avoid or resolve conflicts. This improves work efficiency, increases productivity, and promotes ownership of the solution and shared responsibility. With effective communication, it is also possible to achieve more balanced contributions from the team members. Experts have been included on the team because of their relevant expertise, and so incorporating the diverse contributions from all members will enhance the quality of the solution and reduce the chances of overlooking or underestimating an important aspect of the problem (Olson, Parayitam, and Bao 2007). To improve communications between subject matter experts, it is helpful for statisticians to ask a lot
of questions to broaden their understanding of subject knowledge and background information. By having the entire team hear the answers to these fundamental questions, collective group knowledge is enhanced. This can enable identification of important considerations and allow the statistician to promote the appropriate use of statistical thinking and methods. This also establishes an environment of genuine curiosity that is often reciprocated by other subject matter experts, enabling them to broaden their understanding of proposed statistical methods. With well-established communication channels, statisticians have opportunities to understand the current practice, challenge the relevance of the status quo for the problem at hand, and offer suggestions on how to tailor solutions to match the project goals. Boroto and Zahn (1989) state that the “bulk of the statistician’s job is… building effective relationships,” where “an effective statistician is essentially a skillful translator.”

It is not uncommon for experts from different areas to have difficulty in communication, and it is challenging to build a communication environment that aligns with different expertise. Each discipline can have a unique “language” with technical jargon often having hidden connotations. This can hinder effective communication of the details of their assumptions, methods, and results. It is not surprising that people talking in different “languages” using discipline-specific terminology have a hard time understanding each other. Therefore, for the statisticians to have more effective communication with other subject matter experts, it is helpful to avoid or limit the use of jargon (Anderson-Cook, Lu, and Morzinski 2010).

When discipline-specific terminology is used, it is important to make sure it is clearly defined to avoid misinterpretation. When expressing statistical concepts, it is helpful to explain them from the first principles without unspoken assumptions. Patience and empathy for gaps in background and understanding of discipline-specific principles are important for clear and comfortable communication.

An important skill for successful communication is to listen effectively. This allows us to gain information, understand, and learn. It also helps avoid misunderstanding and reduce unnecessary conflicts and hence has a large impact on the team productivity as well as team relationships. One way to improve your listening skills is to practice “active listening,” by engaging with the speaker to ask questions, clarify concepts, and connect their comments to the task of the group. For statisticians, “active listening” means showing genuine interest in subjective matter knowledge and information, reflecting on what was heard and its relevance, identifying the decisions and outcomes sought, and looking for key messages that impact the choice of what data to collect and how to best analyze it.

**Execution**

The last key element to effective collaboration is attention to the complete and faithful execution of the team plan to implement the best available solution. To deliver effective solutions, statisticians strive to ensure the right data are collected with adequate accuracy and the required precision. Careful attention to the measurement system used to obtain the data, designed experiments or other data collection strategies for answering the right questions, and the most appropriate statistical analysis are key contributions to effective solutions. Statisticians should not limit their participation on the team to only offering technical or methodological support, but should stay connected to the implementation of the solutions. For example, it is important to ensure the designed experiment realistically matches the available time frame and resource, and the actual experiment is implemented the way it was planned (Freeman et al. 2013; Simpson, Listak, and Hutto 2013). After the data are collected and analyzed, statisticians play a key role in helping the subject matter experts translate the analysis results into practical conclusions that can lead to useful decisions and actions in the context of the project objectives. It is not uncommon to encounter unanticipated complications in the execution of the action plans. Statisticians need to expect potential complications and be prepared for managing changes or making corrections, quickly adapt for unanticipated situations, and adjust their strategies for accommodating real complications or solving new challenges. In addition, statisticians can help leverage what has been learned and make a further connection to long-term team objectives. This can help develop future plans and strategies to benefit the organization, which has the positive by-product of enhancing the reputation of statisticians and increasing their acceptance and involvement in future projects.

**A detailed collaboration example**

In this section, we include an example from our experience that illustrates the loss of efficiency from suboptimal collaboration, as well as provides some lessons learned that might have helped produce a better version of interdisciplinary teamwork.
An ineffective collaboration

First, we share an example from one of the authors (CAC) from a project earlier in her career involving reliability assessment for complex systems as a function of age and usage with team members from Los Alamos National Laboratory (LANL) and a branch of the Department of Defense (DoD). Since full-system tests for munitions are destructive and very expensive, a group of statisticians was involved in the project to use available component and subsystem level tests to enhance the analysis (Anderson-Cook et al. 2007, 2008). To effectively use this information, the reliability and design engineers of the system provided detailed information about how the components were combined into subsystems, and how those subsystems needed to perform in a successful test. The statisticians on the team developed a Bayesian analysis approach to allow for data to be combined and expert knowledge of the component and subsystem reliabilities from similar systems to be leveraged.

The project began with the manager of the DoD team members directing them to collaborate with LANL after a presentation on our emerging methodology. Hence, a team was formed with some reluctant participants – they already had a method for estimating reliability that was deeply entrenched in their processes with standardized reporting and general acceptance of results. This reluctance to change has resulted in a lack of commitment to new solutions and project goals.

As the team began meeting, our specified goal was to obtain “improved reliability estimates” using the new approach. The ambiguity of this definition was later revealed since DoD team interpreted improvement as strictly a reduction in the uncertainty in the estimated reliability curves for systems of any age. As statisticians, we were slow to realize that initial increases in the width of uncertainty intervals, caused by combining disparate sources of data, were viewed as a failure of the approach. As statisticians, we accepted that discrepancies between data sources might lead to contradictions at different levels of the system, and did not recognize how these results would be viewed as problematic to the management of the stockpile of systems. By failing to grasp the implications of the results, it was easy to be perceived as out of touch with programmatic priorities. This lack of shared common goals meant that our criteria for success were different, and hence progress in the project was interpreted very differently. The statisticians also lost an opportunity with this lack of understanding, since the differences in our perceptions were interpreted as a lack of respect for their deliverables and historical work. We also felt that our contributions were not being respected as valuable.

In addition, the change from established approaches and reporting potentially represented a substantial disruption to their jobs. One DoD reliability engineer was threatened by the potential of losing control over their reliability program, by having their methods for assessing reliability changed to a more complicated analysis that would make them dependent on statistical methods that were beyond their technical training. This resulted in a lack of trust in the group, which led to the team pulling in separate directions when there were complications and setbacks in the process of developing and implementing the method. If the new method failed, returning to the status quo became an option, and this compromised the commitment of the group to make progress and seriously affected the implementation and execution of the team plans and decisions.

The team also failed to establish sensible ground rules for how to communicate as a team throughout the process. On several occasions when difficulties or setbacks arose, DoD members of the team escalated the problems by complaining to their managers. A simple technical problem then involved multiple layers of managers and led to existential threats to the project. This tendency to escalate the conflict and draw in non-team members meant that the team remained a group of individuals with their own agendas that often dominated the process rather than focusing on solving the problem. The loss of trust from broken confidences hindered future stages of the project. When results were presented outside the team, there was little collective ownership of the solution, with team members often eager to highlight their own efforts, pointing out shortcomings of the solution or attributing problems to other individual team members.

The team was ultimately able to provide a satisfactory outcome at the conclusion of the project, but the process was tension-filled and inefficiently executed, with the collaboration terminating before all potential enhancements to the effort had been thoroughly explored.

Lessons learned from a flawed collaboration

In reflecting on this team collaboration, there were a number of important lessons that were learned. We highlight several of these that could have improved the quality of the collaboration and lead to a more satisfying final outcome. Being able to effectively manage changes, with their emotional and workload consequences, would have enabled the technical aspects
of the project to remain more in the forefront and less hindered by team dynamics.

1. In the early stages of the collaboration, it would have been beneficial for the statistical team to work harder to understand the status quo of reliability assessment for the DoD team. This would have given us a greater appreciation for the priorities of the engineers. Paramount to their comfort with the process was ensuring that they fully understood and were comfortable reporting the results to their supervisors. If the consequences of change had been fully understood, then direct discussions would have been possible to encourage the full commitment of all team members to the process.

2. An initial investment in developing respect and trust among team members would have improved the process. It is not unusual to start a team collaboration with members of diverse backgrounds and lack of understanding and appreciation of other parts of the project. Hence, it is a useful investment to dedicate time at the beginning of the project on filling in gaps and building common ground that will benefit all aspects of the project process in the future. It would have been more helpful to directly discuss how changes to the process could impact the job descriptions of some of the team members, or even individual careers and actively addressing these concerns. Being open and honest about potential concerns or conflicts at the beginning can help build trust, improve communication, and increase commitment to the project goals.

3. One of the clear failures of the team was to not explicitly identify how project success should be defined. By using a subjective expression of “improving the reliability estimate” with no associated quantitative metrics for what improvement meant, the team allowed differences in interpretation to persist well into the solution development stage. At the point where the confusion was discovered, many team members felt a sense of betrayal at having worked at cross-purposes for an extended time. Starting the project well with clearly stated shared common goals and discussion of individual understanding and views would have uncovered potential discrepancies, brought the team together, and provided a strong focus for future tasks. Having too narrow of a focus on just the technical aspects of the problem and not the potential to disrupt the processes and routines of some members of the team led to inefficiencies that plagued progress.

4. An approach to building mutual respect among team members early in the process should have been employed for both reliability engineers and statisticians to share key background and knowledge among the team. With additional discussions from the reliability engineers about the system and current reporting practices, there would have been improved potential to focus on how new solutions would fit into this framework. By statisticians sharing more of the technical backgrounds of the Bayesian analysis early, a greater comfort for collectively owning the new solution would have been possible.

5. Establishing working ground rules for communication as a team would have reduced the drama of interactions. Early on in the process, talking through protocols for how disputes should be handled, how results from the project should be reported by the team, and encouraging team ownership of all decisions would have strengthened the impact of the work. If the pattern of raising problems to outside management had been initiated by some team members, it would be helpful to revisit the agreed-upon protocols for the team and discussing how they impact team dynamics and effectiveness. A commitment to abiding by the collective ownership of the successes and struggles of the project would have increased trust within the group and improved management buy-in for the results and increased the impact of results.

6. Starting well is critically important. In the early stages of the project, attention to process and the potential for tension were not taken seriously enough. The statisticians could have done a better job of understanding more about the background and status quo and anticipating where conflict might arise. With a bigger investment in understanding the priorities, strengths, and weaknesses that all team members were bringing to the project, the fundamentals of a productive and fruitful collaboration could have been established early.

7. Avoid being naïve or passive. When problems with the productivity and team dynamics started to emerge, the issues should have been addressed immediately. The statisticians were slow to identify root causes of problems and reluctant to intervene immediately to address them directly. Healthy team dynamics require active nurturing and vigilance. If there are issues that are
beginning to develop, they need to be discussed and resolved before they become more substantial issues.

8. Incorporate team self-assessment strategies throughout the project lifetime (Snee, Kelleher, and Reynard 1998). By building in discussion and opportunities to reflect on how the team is performing, it would enable some difficult conversations about problems with the team at earlier stages and prevent them from escalating.

**How should statisticians prepare**

Given the fundamentals presented previously, we now provide suggestions on how statisticians, particularly early career, can develop a key set of nonstatistical skills (Snee 1998) for being an effective collaborator on a well-functioning interdisciplinary team. We strongly believe that while excellence in many of these skills will take considerable efforts, it is important to make maximal contributions to a team that all statisticians strive to improve in these areas. We have divided our suggestions into five categories with a range of levels within each category. Also we organize our discussions based on positives to which to aspire and negatives to avoid when involved in collaborative teamwork within each category.

**Share well**

The first step toward being an effective collaborator is to communicate statistical ideas well to other team members from diverse backgrounds. Being able to share technical expertise well and explain the concepts and fundamentals of statistical thinking and statistical engineering can help others on the team absorb the key messages about data acquisition and statistical analyses, and be able to effectively use the information to make better team decisions. A common mistake for early career statisticians is to use technical jargons and terminology to explain basic statistical concepts and ideas to people outside of our field. This may cause others to lose interest and lead to missed opportunities to introduce and/or reinforce broader statistical ideas for reaching improved solutions. Being able to share technical concepts in everyday language can increase the likelihood of a positive impact and discipline respect. It is also helpful to be sensitive to different connotations for some keywords (such as “design,” “model,” “parameters”) across different disciplines (Anderson-Cook, Lu, and Morzinski 2010). One strategy to practice these skills is to prepare “elevator speeches” for explaining basic statistical concepts and tools, which will help to smooth the intercommunication, stimulate interests, and improve acceptance.

Highlighting the key differences between approaches and clearly communicating the important assumptions and how they are connected to practical problems helps other team members quickly grasp the central messages and their relevance to the shared common goals of the team. Discussing different options and using efficient graphical or numerical summaries to provide informative quantitative comparisons can facilitate richer discussion and improved understanding of different aspects of a complex decision (Anderson-Cook and Lu 2018). Statisticians should avoid overselling a method or solution without talking about its assumptions and practical implications. During discussions of data acquisition and the analysis, it is helpful to initially present comparisons and results as objectively as possible and to defer expressing subjective preferences until later during broader discussions of what actions should be taken based on results and choices.

**Participate fully**

In addition to effectively communicating statistical ideas and facilitating discussion, being a good collaborator on an interdisciplinary team also requires statisticians to build a high level of appreciation and core understanding of the subject matter outside of their own specialty area to efficiently receive and incorporate important domain knowledge. The details of the subject matter domain are often essential components of what constitutes the best solution, and hence a core understanding of the fundamentals of the problem can enable statisticians to make better suggestions. In many applications, understanding the assumptions, limitations, and logistic constraints on the problems are important for precisely defining the scope of the problem, choosing the appropriate metrics for capturing important information, collecting the most relevant data, and selecting appropriate methods to solve the right problem. While experience is a key component of improving these active listening skills to extract what are important priorities and constraints of a problem, discussion with more experienced statisticians about their strategies can help accelerate learning. If there are several statisticians on a team, discussions before and after the meeting about key messages to be delivered and a debrief after an interdisciplinary team meeting about what others heard can help organize the information, clarify questions, and correct misunderstandings.
Also, building curiosity in other subject areas can improve how we receive information from outside of our specialty area, allowing more active engagement in team discussion, and also building a connection with others. Statisticians can help develop their scientific and engineering backgrounds by reading and attending presentations on research outside of their area of specialization. During these opportunities, it can be helpful to think or ask about how the research can have an impact and solve important problems, as well as thinking about how statistical methods can enhance the work being done. It is also beneficial to build friendships with colleagues from other disciplines and to share expertise and develop questioning techniques about how to extract the important questions and problems in their research area. Practicing this in a casual setting will make these interactions in team collaborations less intimidating and more comfortable.

Another important consideration to receiving information well is to build a deep appreciation for the points of stress and challenges that are prominent in different disciplines. Understanding what is truly difficult in a research area and why it is hard builds empathy for team members and their challenges, and also helps focus where statistical contributions can be most appreciated. A common area where it is helpful to have thoughtful awareness is the cost and effort required to collect high-quality, relevant data. If we have an understanding of problems that have been ongoing struggles toward progress, then it is easier to have a sense of what solutions are likely to be valued.

**Tailor message to match the framework**

The degree of impact we can make is often dependent on how we deliver our message. Tailoring our message to match the corporate culture and project goals and making our message resonate with individual members of the team can greatly improve how it is received. Many of us have had the experience of seeing a statistically sound solution being ignored, when technically it may have been the right approach. Both the solution itself and its presentation can be the reason for it not being adopted. To understand the culture of our organization requires familiarity with the work environment, how the organization operates, and listening to key messages sent from the top of the organization. It is beneficial to actively observe how people function and interact with each other, and understand the organization’s mission, value, and ethics. To develop applicable, broadly accepted solutions requires exploration of past choices, understanding of what succeeded, what failed, and the reasons behind these outcomes. This can avoid similar mistakes and guide the development of more viable solutions, which are a good match for the priorities of the organization. In addition, statisticians can make a useful impact not only through successful adoption of a statistical solution, but also through effectively communicating the strength and weakness of alternative solutions and the limitations in the conclusions and decisions.

Before presenting potential solutions, it is helpful to play the devil’s advocate to analyze possible sticking points and where the proposed solution does not completely address current needs. By anticipating limitations of an approach, it is often possible to refine it and provide a better match to the current needs and also soften conflicts by guiding discussion to objectively consider strengths and weaknesses of alternatives. Data-centric assessment of alternatives can help reduce conflict and build toward team agreement. Statisticians can have one-on-one discussions with key members of the team to help understand the appropriateness of their proposed solutions, before presenting to the larger group and to assess management support. Statisticians can use quantitative summaries and powerful graphics to help convey important messages in an intuitive and effective way for securing team buy-in for potential solutions.

**Facilitate/lead the process**

Building structure into complicated problem-solving and decision-making processes is a key to staying on task and reducing nonproductive disagreements. Structured decision-making can be more effective in accommodating different priorities and use data to drive transparent and defensible decisions. The define–measure–analyze–improve–control (DMAIC) problem-solving model and the define–measure–reduce–combine–select (DMRCS) decision-making process encourage structure in tackling real problems. Statisticians equipped with knowledge of these powerful tools and methods can facilitate or lead. A team is more likely to participate fully in each step of the process if they understand the overall flow that will be followed and understand the steps of the process where their opinions and priorities will be formally included.

To build experience with the DMAIC and DMRCS processes, it is helpful to practice these skills and their associated tools with problem-solving and decision-making outside of the team environment. Walking through the steps for smaller problems can reinforce
the structure of the approaches and provide insights about how the tools can be effectively incorporated. For example, using DMAIC for a complicated home improvement project or DMRC for a multifaceted purchase (like a car or home) can provide useful experience. Key areas on which to focus include ensuring the right questions and good quality data are used for delivering useful solutions, clearly conveying the best options given different priorities, and quantifying their relative performance to encourage comparison and discussion. With this additional experience, it will become easier to talk effectively about the process strategies, advantages, and steps for solving complex problems. A structured process increases the transparency of the decision, promotes maximum team consensus, and can build sustained long-term team support of the decision from the team members.

To play a key role in leading and facilitating a team, leadership experience is important. Being prepared to lead a team or segments of the process will help encourage full participation on the team and transition from being a consultant to a collaborator (Snee and Hoerl 2004). To prepare, find opportunities at work and outside of work to practice leading and managing conflicts effectively. Volunteer organizations provide an excellent forum for these opportunities, and in addition to providing service to a community, they can often be less contentious places to begin to develop these skills. In addition, statisticians can make impactful contributions by mentoring members of the team about the general process and how to incorporate data-driven problem-solving skills for finding the best-available solutions.

**Embrace cognitive diversity**

Cognitive diversity can be a powerful accelerator for developing more efficient, innovative, and better solutions. Statisticians need to embrace cognitive diversity to be a better member or a leader of a cognitively diverse team. To embrace the diverse perspectives of team members, statisticians should train themselves to actively listen to the different ways of viewing and approaching problems. Historically, much of statistical training focuses on objective aspects of problems, while often ignoring or minimizing the role of subjective choices and preferences. Developing an awareness of the difference between the objective (right/wrong) and subjective (preference) parts of the collaboration can guide how the discussion is approached. A particular statistical approach is only best if it is a good match for all of the assumptions it relies upon.

When there is an imperfect fit between method assumptions and the problem to be solved, an important subjective discussion may involve how to choose between several imperfect choices to minimize the risks and maximize the potential benefits. Listening to different opinions and concerns can soften the disagreements and lead to a more balanced assessment of tradeoffs.

The clear presentation of alternatives and their relative strengths and weaknesses can bring people of different views to the same table for meaningful discussions. To embrace diverse interpretations of information, the statisticians need to leverage the power of various analytic and graphical tools to deliver visualizations and summaries to encourage productive discussion. To develop these skills, it is helpful to focus on visualizations and summaries when preparing for presentations. Actively exploring different ways of presenting the same information and understanding how they are received by different groups of audience can help build empathy for how others receive information and select the right strategy for precisely delivering the intended messages.

A beneficial complement to individual problem-solving and decision-making is to find a thought partner (Stanny 2012) for important areas of your work and personal life. A key aspect of a thought partner is their ability to challenge your thinking and fundamental assumptions about the problem and its potential solutions. Ideally, this is someone with whom comfortable interactions are straightforward, but who views the world quite differently. Being encouraged to articulate your basic assumptions and defend them can build skills for improved clarity of thinking, embracing broader alternatives and better ability to choose between choices.

By working on developing this collection of skills, not only will your ability to collaborate effectively on an interdisciplinary team improve, but there is good potential to increase your influence and contributions in many aspects of your personal and professional life.

**Conclusions**

In this article, we have presented fundamental elements of interdisciplinary teamwork that can make collaboration more efficient and effective for solving complex and challenging problems. We have focused on some of the particular aspects that are relevant to statisticians’ role, perception, and participation on a diverse team and how they can inspire statisticians for being more effective collaborators or even team
leaders. While our focus has been on these applications, clearly many of the principles for building efficient, productive teams and interacting well within the team are broadly applicable to many types of collaborative efforts.

We have leveraged collaboration and team-building literature from other disciplines and adapted their messages to the unique challenges that statisticians have when working on a multidisciplinary team. In addition, since much of the statistics curriculum at major universities focus on statistical methods and tools, with relatively little emphasis on developing these collaboration skills, we have provided some guidance for early career statisticians on how they can begin the process of developing and enhancing collaboration and statistical engineering skills for team problem-solving and decision-making.

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