2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37151

Board 286: ”Exploring Other People’s Mind, Exploring Your Own Mind” —A Story of Divergent Thinking from Mechanical Engineering Practice

Laura R. Murphy, University of Michigan

Laura is a PhD Candidate in Design Science at the University of Michigan, Ann Arbor. Her work investigates inclusive design processes, developing strategies for practicing engineers to more deeply account for diverse perspectives during design activities.

Dr. Shanna R. Daly, University of Michigan

Shanna Daly is an Associate Professor in Mechanical Engineering at the University of Michigan. She has a B.E. in Chemical Engineering from the University of Dayton and a Ph.D. in Engineering Education from Purdue University.

Thanina Makhlouf,
Dr. Colleen M. Seifert, University of Michigan

Colleen M. Seifert is an Arthur F. Thurnau Professor in the Department of Psychology at the University of Michigan. She received her Ph.D. in psychology at Yale University. She was an ASEE postdoctoral fellow at the University of California â€” San Diego

"Exploring other people's mind, exploring your own mind:" A Story of Divergent Thinking from Mechanical Engineering Practice

Abstract

Divergent thinking is the process of exploring many options and perspectives and is a key part of effective and inclusive engineering outcomes. In engineering education, divergent exploration is often applied within idea generation; however, many other stages in engineering projects may benefit from divergent exploration, such as defining problems, identifying stakeholders, selecting problem solving approaches, and understanding potential implications of engineering decisions. Professional engineers often struggle to identify and manage diverse perspectives, and little is known about the practice of divergent exploration in engineering projects. To investigate, we interviewed a mechanical engineer about her exploration practices in a past professional project. From her striking examples of divergent thinking and barriers to its practice, we constructed a narrative-based educational tool for students, educators, and practitioners. The engineer's first-hand experiences demonstrate that to think divergently, engineers must understand system constraints, explore widely, seek information from many sources, take risks, seek varied perspectives, and explore multiple methods to solve problems.

Introduction

Exploring many options is key to developing innovative and inclusive engineering solutions for complex systems, diverse stakeholders, and "wicked" problems [1], [2]. However, research has shown that engineers often focus on finding a single solution rather than exploring multiple potential solutions, methods, perspectives, and even problems during their problem solving [3], [4]. The broad exploration of many diverse options is also known as *divergent thinking* [5]. Studies show the benefits of broadening perspectives [4], [6], considering alternatives [7], [8], and exploring unknowns [9]. Engineering education often focuses on traditional technical skills [10] without introducing tools, training, and support needed to teach student engineers how to incorporate divergent thinking. Advancing divergent thinking in engineering education can be supported by increasing recognition of the value of divergent thinking in engineering and making visible how divergent thinking currently occurs in practice.

To support the advancement of divergent thinking, we present an account from an engineer describing her own experiences with divergent thinking on the job. To develop an account grounded in engineering practice, we interviewed a mechanical engineering practitioner who described how she leveraged divergent thinking across her engineering problem solving. We asked about experiences with divergent thinking in conducting background research and identifying stakeholders, finding problem solving strategies, and understanding potential implications of engineering decisions. In this paper, we present an account of her experiences highlighting factors that impacted her ability to engage in divergent thinking in engineering problem solving.

Background

Divergent thinking is defined as the process of exploring many diverse options, alternatives, and perspectives [1], [5]. Divergent thinking opens a potential for more creative outcomes [11] because considering more diverse options increases the chance that the final selected option is a more creative one. Divergent thinking is a key characteristic in creativity [12]. It has been shown important in solving complex problems creatively and generating more innovative outcomes [1], [2]. Divergent thinking is often considered during idea generation through generating many potential solutions to a problem [13], [14]. In response to engineers' struggles with design fixation during idea generation [7], [15], [16], many ideation tools have been created to support generation of diverse ideas, such as Brainstorming [17], Design Heuristics [18], and TRIZ [19]. However, divergent thinking can occur across many areas of engineering problem solving. Engineers might leverage divergent thinking when developing their understanding of the problem and its context, identifying stakeholders, or exploring potential problem-solving methods and strategies [9].

As educational tools, stories have been employed to convey complex factors that impact engineering solutions in practice, such as ethics [20], conflicting technical requirements [21], sustainable development [22], and the human impacts of engineering decisions [23]. Accounts of how individual engineers have pursued divergent thinking in their workplace may be helpful pedagogical tools for engineering students to better understand its importance and motivate efforts to learn more. One study found that instructors with industry experience and therefore real-life stories made essential contributions to connecting lessons in the classroom to practical applications [24]. Divergent thinking stories may similarly support complex outcomes to normalize divergent thinking as an importance practice for engineers and support relevant skill development.

Method

Our goal was to better understand how engineers leverage divergent thinking during problem solving in practice to learn about the value of divergent thinking and barriers that might prevent its occurrence.

Data collection

Data were collected from practitioners through interviews as part of a larger project on divergent thinking in engineering. Engineers were asked to discuss a specific past engineering project and how they explored multiple options or perspectives across that project. We selected one participant's interview to present in this paper who demonstrated many striking examples of divergent thinking and its barriers across her engineering work. The interview included questions about divergent thinking while identifying potential problem solving strategies, conducting background research, identifying stakeholders, and understanding potential implications of engineering decisions. Additional information about the protocol development process is described by Clancy and colleagues [25].

Data analysis

One researcher transcribed the interview and highlighted excerpts where the engineer demonstrated or illustrated barriers to divergent thinking. Two other researchers listened to the practitioner interview and validated the relevance of the identified segments for divergent exploration. Segments were then selected to capture differing aspects of exploration. Following recommendations of qualitative analysis [26] and similar narrative-based educational tools [27], we constructed a narrative linking the selected segments. The resulting narrative includes a subset of divergent exploration described by the practitioner to represent major themes of the interview, including understanding system constraints, exploring widely, seeking information and varied perspectives from many sources, and taking risks to successfully solve engineering problems.

Narrative: Radha

Radha (pseudonym) is a Southeast Asian woman who at the time of the interview had worked as a mechanical engineer in the U.S. for 11 years. She has held several professional roles in her career across the energy and automotive industries. At the time of the interview, she was a crash safety engineer at a major automotive company.

In describing her current role, Radha stressed how important it was to understand the impact her work was going to have on other parts of the system. In her engineering context of crash safety testing, this 'system' was the entire vehicle and its launch. She described how, "*especially as mechanical engineer[s], we're very prone to look at parts, right?...We are really important, but again, we're just part of it."* She identified the dynamic between knowing her work was a part, but not the whole, of a project in her context of crash safety testing:

> *"If you don't understand how everything connects in the vehicle, it makes it difficult for you. So that was part of unsuccessfulness initially because* ***I didn't understand the system****. So knowing your product when I talk about this initially is really important. Learning your product is really important. You can't just sit and learn a little bit, like, your own part.* ***You have to also understand the overarching goal of your project. How do you fit in that overall project?*** *So, you know engine is there, but [the] project, meaning the vehicle, is this much. How does that fit in? How does it affect everything else, right?"*

As a young engineer, Radha felt she learned a lot of theory in her undergraduate engineering training, but that she lacked a lot of the practical information she needed to be successful at her job. She acknowledged these gaps in her knowledge:

> *"But I read. I watched YouTube videos. Okay. Diesel engine works****. Okay. How does transmission, like what does transmission do? Right? It sounds stupid now.*** *Right? But like, I mean, I tell you I was really not into that part of cars, how they work. I understood the mechanics. If you put [it] together, I can tell you and I can calculate, but like how every automobile…It was a shock. I was so bad. And*

> *I know I'm a mechanical engineer and it sounds bad, but like I was that bad. You know, like what is a shock? Now you talk with me, okay, I can point out everything on the truck. But what is the suspension like? [I] didn't know so [I] read up on it. But it wasn't enough because it was more learning on the job as you go."*

Radha decided to actively seek out many different sources of information to learn what she needed to be successful in her engineering work. She read, she watched YouTube videos, and she talked to many people in her company. Sometimes, her search for information prompted her to find her own hands-on experience rather than relying on theoretical information alone:

> *"I'm a person who likes to just have information. So what I'll do is I'll go look at the vehicle, right? Know what the different parts are. Ask, what does this do? Right? What is the difference between four by four versus four by two?* ***I know in theory, right? But I want to go see these parts."***

When dealing with a particularly complex new problem, she acknowledged she even had to generate new knowledge through testing: *"There's no book for that. You just have to go test for it."* Similarly, to inform and guide her engineering work, Radha described seeking and developing relationships with people with varying perspectives and expertise. She described: ***"****Okay. This is something I don't know.* ***It's not my right area. I gotta ask XYZ engineer because he's an expert in it.****"* She developed a practice of explicitly comparing her own perspective -- what she thinks -- to other people's opinions in order to make more informed engineering decisions. She did not simply accept the expert's advice without question, but brought a critical lens to their perspectives and then used her own judgment to move forward with her decision.

> *"And it sometimes takes interviewing people, 'Okay, this is sort of what I'm doing. What do you think?' And then they'll say something. It could click with you and it will be like, 'Oh, this totally…we need to do that, right?' I didn't think of it, but again,* ***exploring other people's mind, exploring your own mind. Write down what you think, write down what they think, compare your notes****."*

To have a network of experts to consult when needed, Radha invested time and energy into developing great professional relationships at work. She spent time with others to learn how they approached different problems in varied contexts: *"I would sit with other people and it was not my project, but* ***I would go and sit with them and learn what they're doing****. And that's how I started learning about the vehicles."* She talked about the importance of understanding the roles and perspectives of her immediate teammates and customers: *"We were only a few engineers. So if one engineer's down, I'm doing their job. So you had to learn. So what I started to do is I started following people, asking questions, and going out to the customer and actually just spending time [with them]."*

Radha applied her new knowledge from many diverse sources when choosing strategies to solve her own given problems. She described pursuing multiple approaches to avoid "putting all her eggs in one basket." She found that pursuing many problem solving strategies helped her come to a great solution in the shortest amount of time:

> *"So you have problem [solving] strategies, right? So you have couple of options. First of all, you can do your own research and come up with a solution. Or you can bring an expert and ask them. Or you have to work together, identify the problem first, come up with a reasonable solution, get an expert and then work towards them…* ***So it's not that you are just looking for one avenue when you [are] going with the problem [solving] strategy. You've got to explore 1, 2, 3….*** *And then we'll be like, 'Okay, we're having this other avenue.' And you're like, 'Why are you exploring so many at the same time? Why don't you wait for an answer?' Because there is no waiting time because the longer you wait, the longer that the product is just staying there and you're losing money and you're losing time to test that vehicle."*

Throughout the interview, Radha emphasized how important it was to 'put herself out there' and overcome fear of judgment and rejection. Especially as a young engineer, she felt pressure to avoid showing any faults or weaknesses:

> *"First of all, I didn't ask many questions. So I tried to read books because I was shy and I wanted to be good at my job, but I didn't want other people to think I didn't know what I was doing even though as the young engineer, I think you have that. Well, some people do. I had that* ***. I wanted to learn everything on my own and not sound stupid."***

Radha reached a turning point in her journey towards empowerment and self-confidence as an engineer when she realized she had to stand up for her own engineering perspective despite everyone else in the situation holding a different one:

> *"And I think it was one day I went to the customer. And there's this engine plug-in. They're saying the car is not starting. And there was this plug that was not connected. And I kept on going back to it and they kept on telling me because again, I didn't have any support. I was the only person there and I was not confident but I'm like, 'do me a favor. Disconnect it and plug it back in.' Right? We're spending hours at this point. Engine was not turning on and it was just that connection was not plugged in properly. And all I had to do is I had to have enough courage to tell them to do that, right?* ***So sometimes your own inhibitions make you unsuccessful and sometimes you don't know enough, but you gotta, "okay, just do it for me."*** *And they were not happy because it was like, you know, they were hourly workers. It's 3:15. I'm getting out in 15 minutes. I'm like, 'Please just, it will solve problem for me for you.' And they did it and the engine started and we were done in five minutes and I packed my bags and we went.* ***And I think that was just a turning point for me where I was just like, stop being scared, you know, you can be good at it if you just follow your instincts sometime."***

Across her engineering practice, Radha follows this process of initiating opportunities to learn from multiple people, projects, and experiences while solving engineering problems. She describes this divergent exploration as key to her success in projects because it allows her to build upon her own ideas by making room for influence from other perspectives. This suggests a role for divergent exploration throughout the engineering process as a way of thinking to arrive at the best solutions.

Discussion

Radha's first-hand experiences highlight several potential takeaways for students and engineering educators: to think divergently, engineers have to understand system constraints, explore widely, seek information from many sources, take risks, seek varied perspectives, and explore multiple methods to solve problems.

The narrative highlights that it is important for engineers to understand the ways in which their work is part of a larger environment. Many engineers work on a small part of a bigger product: they work on the brake system of a car or develop the mounting system for electrical components in a satellite. While the engineering decisions one engineer makes must be centered in their specific context and grounded in specific requirements, Radha described how engineers also must account for the way their decisions relate to other parts of the system, and the system as a whole. Many sources call for the emphasis on systems thinking in engineering education [28], [29] and propose methods to promote and assess systems thinking [30], [31]. Divergently considering potential implications of engineering decisions and exploring the problem context can be one way to facilitate engineers knowing what decisions are being made in other areas of the project system.

Radha had personal barriers she had to overcome within herself and in the relationships she needed to establish with others. She had to acknowledge gaps in her knowledge and then actively seek out many types of information from many distinct sources. The divergent thinking that took place centered on investing time into background research and looking to many sources of information rather than a single source. She also had to put herself 'out there' and overcome fear of judgment and rejection in order to be successful. Her story about asserting her perspective while solving an engineering problem in particular aligns with an aspect of Treffinger's [12] characteristics of creativity: listening to one's 'inner voice' even when it goes against group-think. It was a risk for her to overcome her fear and assert her perspective, but successful divergent thinking can involve taking on more risk [32].

Radha prioritized building relationships to gather diverse perspectives from people with varied expertise. A key part of successful divergent thinking for her was the network of diverse colleagues she had already established and continued to build. Her engineering decisions, therefore, were informed by divergent perspectives and varying expertise. Building such a network seemed to depend on the initiative of the individual engineer as well as the cultural norms of her work environment. If a work environment is not already diverse in perspectives and expertise, or if engineers are (implicitly or explicitly) discouraged from engaging with people outside their immediate team, divergently exploring perspectives may be much more difficult to achieve.

Radha explicitly described how important it was for her to explore and pursue many problem-solving approaches. Therefore, her process was not a simple, linear one. Rather, her process involved divergently exploring many ways to solve a problem as effectively and efficiently as possible. This type of a process looks quite different than the linear processes engineering students are often taught [33], [34] and may require educators to expand the types of processes included in the classroom to make room for divergent thinking.

Limitations

Our understanding of Radha's experiences with divergent thinking was limited to a single one-time interview focusing on an engineering project. We may have generated different insights over time or through collected stories across many projects. To create the narrative-based educational tool, we chose a deep dive into a single engineer's project for a more concentrated focus on experiences across a project. Finally, the interview collected only Radha's perception of success and divergence on the project. It is possible that triangulating the perspectives of her teammates may have provided additional context to interpret her experiences.

Implications

Radha's story can stand alone as a valuable education tool to convey the complex nature of teaching and practicing divergent thinking. Engineering stories may play an important role in broadening perspectives on what engineers can do in practice and how it may differ from the "textbook" process taught in classrooms. Teaching through case stories has been shown effective in connecting students to the complexity of 'real life' outside of the classroom [35]. Radha's story and others like it may support instructors in supporting students as they make that connection during their studies. Each student who encounters Radha's story will take away their own contextualized interpretation of the importance of divergent thinking as well as how to foster based on their own lived engineering experiences.

Future Work

Future work will compare experiences described by other practitioners in interviews with the same protocol. By examining how divergent thinking occurs across many contexts during practice, its importance and execution can be supported in engineering education. Future work will identify more collections of divergent exploration stories to leverage in engineering classrooms.

Conclusion

This paper presents a constructed narrative describing a mechanical engineer's experiences with divergent thinking in practice. The case describes the complexity of engineering practice and the many social, emotional, and technical considerations contributing to successful project outcomes. Several strategies emerge from the account that appear to support divergent thinking, along with perceived barriers to divergence in approaches. Examples in the engineer's own words illustrate challenges including workplace environments, personal qualities such as identity and self-confidence, and the larger sociotechnical systems of engineering work. This engineer's story demonstrates multiple roles for divergent thinking on projects, and serves to inform and motivate students to consider alternative approaches while solving engineering problems.

References

[1] M. Ames and M. Runco, "Predicting entrepreneurship from ideation and divergent thinking," *Creativity and Innovation Management*, vol. 14, no. 3, pp. 311–315, 2005.

[2] K. Wolf and H. Mieg, "Cognitive determinants of the success of inventors: Complex problem solving and deliberate use of divergent and convergent thinking," *European Journal of Cognitive Psychology*, vol. 22, no. 3, pp. 443–462, 2010.

[3] J. W. Lee, S. Daly, A. Huang-Saad, and C. Seifert, "Divergence in Problems Rather Than Solutions: Design Processes of Microfluidic Engineers in Academia," in *ASME 2018 International Design Engineering Technical Conferences (IDETC)*, Quebec City, Canada, 2018.

[4] J. A. Studer, S. R. Daly, S. McKilligan, and C. M. Seifert, "Evidence of problem exploration in creative designs," *AI EDAM*, vol. 32, no. 4, pp. 415–430, Nov. 2018, doi: 10.1017/S0890060418000124.

[5] D. R. Brophy, "Comparing the attributes, activities, and performance of divergent, convergent, and combination thinkers," *Creativity Research Journal*, vol. 13, no. 3 & 4, pp. 439–455, 2001.

[6] J. K. Murray, J. A. Studer, S. R. Daly, S. McKilligan, and C. M. Seifert, "Design by taking perspectives: How engineers explore problems," *Journal of Engineering Education*, vol. 108, no. 2, pp. 248–275, 2019, doi: https://doi.org/10.1002/jee.20263.

[7] D. G. Jansson and S. M. Smith, "Design fixation," *Design Studies*, vol. 12, no. 1, pp. 3–11, 1991.

[8] S. Yilmaz, S. R. Daly, C. M. Seifert, and R. Gonzalez, "Evidence-based design heuristics for idea generation," *Design Studies*, vol. 46, pp. 95–124, Sep. 2016, doi: 10.1016/j.destud.2016.05.001.

[9] L. R. Murphy, S. M. Clancy, Daly, S.R., and C. M. Seifert, "Divergent thinking in engineering: Diverse exploration is key to successful project outcomes," in *ASEE Annual Conference & Exposition*, Jun. 2022.

[10] R. Miller, "Why the hard science of engineering is no longer enough to meet the 21st century challenges," *Olin College of Engineering*, 2015.

[11] M. A. Runco and S. Acar, "Divergent Thinking as an Indicator of Creative Potential," *Creativity Research Journal*, vol. 24, no. 1, pp. 66–75, Jan. 2012, doi: 10.1080/10400419.2012.652929.

[12] D. J. Treffinger, G. C. Young, E. C. Shelby, and C. Shepardson, "Assessing creativity: a guide for educators.," University of Connecticut, The National Research Center on the Gifted and Talented, Monograph RM02170, 2002.

[13] S. R. Daly, C. M. Seifert, S. Yilmaz, and R. Gonzalez, "Comparing ideation techniques for beginning designers," *Journal of Mechanical Design*, vol. 138, no. 10, p. 101108, Oct. 2016, doi: 10.1115/1.4034087.

[14] Y.-C. Liu, T. Bligh, and A. Chakrabarti, "Towards an 'ideal' approach for concept generation," *Design Studies*, vol. 24, no. 4, pp. 341–355, Jul. 2003.

[15] K. Leahy, S. R. Daly, S. McKilligan, and C. M. Seifert, "Design fixation from initial examples: Provided versus self-generated ideas," *Journal of Mechanical Design*, vol. 142, no. 10, p. 101402, 2020.

[16] N. Crilly, "Fixation and creativity in concept development: The attitudes and practices of expert designers,"," *Design Studies*, vol. 38, pp. 54–91, 2015.

[17] A. F. Osborn, *Applied imagination: Principles and procedures of creative problem-solving*, 3rd Rev Edition. Buffalo, NY: Scribner, 1963.
[18] S. Yilmaz, C. M. Seifert, J. L. Christian, S. R. Daly, and R. Gonzalez, "Design heuristics observed in innovative products.," Iowa State University and University of Michigan., 2012.
[19] G. Altshuller, *40 principles: TRIZ keys to technical innovation*. Worcester, Mass.: Technical Innovation Center, Inc., 1997.
[20] C. Nicometo, T. Nathans-Kelly, and B. Skarzynski, "Mind the gap: Using lessons learned from practicing engineers to teach engineering ethics to undergraduates," in *IEEE International Symposium on Ethics in Science, Technology, and Engineering*, 2014, pp. 1–7. doi: 10.1109/ETHICS.2014.6893430.
[21] J. W. Blake, "Using stories of technology to teach technological and engineering literacy in courses for majors," in *ASEE Annual Conference & Exposition*, Tampa, FL, 2019. doi: 10.18260/1-2--33518.
[22] G. U. Davis, "The role of case studies for the integration of sustainable development into the education of engineers," *World Transactions on Engineering and Technology Education*, vol. 5, no. 1, 2006.
[23] W. R. Wilson, "Using the Chernobyl incident to teach engineering ethics," *Science and Engineering Ethics*, vol. 19, pp. 624–640, 2013.
[24] C. Arlett, F. Lamb, R. Dales, L. Willis, and E. Hurdle, "Meeting the needs of industry: the drivers for change in engineering education," *Engineering Education*, vol. 5, no. 2, pp. 18–25, 2010, doi: 10.11120/ened.2010.05020018.
[25] S. Clancy, L. R. Murphy, S. R. Daly, and C. M. Seifert, "Developing an interview protocol to elicit engineering students' divergent thinking experiences," presented at the 2022 ASEE Annual Conference & Exposition, 2022.
[26] K. Charmaz, *Constructing Grounded Theory: A practical guide through qualitative analysis*. Sage, 2006.
[27] I. B. Rodriguez-Calero, S. R. Daly, G. Burleson, M. J. Coulentianos, and K. H. Sienko, "Using practitioner strategies to support engineering students' intentional use of prototypes for stakeholder engagement during front-end design," *International Journal of Engineering Education*, vol. 38, no. 6, pp. 1923–1935, 2022.
[28] K. M. Castelle and R. M. Jaradat, "Development of an instrument to assess capacity for systems thinking," *Procedia Computer Science*, vol. 95, pp. 80–86, 2016, doi: https://doi.org/10.1016/j.procs.2016.09.296.
[29] C. D. Mote Jr., D. A. Dowling, and J. Zhou, "The power of an idea: The international impacts of the Grand Challenges for engineering," *Engineering*, vol. 2, no. 1, pp. 4–7, 2016, doi: http://dx.doi.org/10.1016/J.ENG.2016.01.025.
[30] A. T. Bahill and B. Gissing, "Re-evaluating systems engineering concepts using systems thinking," *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews*, vol. 28, no. 4, pp. 516–527, 1998, doi: https://doi.org/10.1109/5326.725338.
[31] K. E. Dugan, E. A. Mosyjowski, S. R. Daly, and L. R. Lattuca, "Systems thinking assessments in engineering: A systematic literature review," *Systems Research and Behavioral Science*, vol. 39, no. 4, pp. 840–866, 2022.
[32] W. Shen, B. Hommel, Y. Yuan, L. Chang, and W. Zhang, "Risk-taking and creativity: Convergent, but not divergent thinking is better in low-risk takers," *Creativity Research*

Journal, vol. 30, no. 2, pp. 224–231, 2018, doi: https://doi.org/10.1080/10400419.2018.1446852.
[33] C. L. Dym and P. Little, *Engineering design: A project-based introduction*, Third. Hoboken, NJ: John Wiley & Sons, 2004.
[34] T. J. Howard, S. J. Culley, and E. Dekoninck, "Describing the creative design process by the integration of engineering design and cognitive psychology literature," *Design Studies*, vol. 29, no. 2, 2008.
[35] L. B. Barnes, C. R. Christensen, and A. J. Hansen, "Teaching with cases at the Harvard Business School," in *Teaching and the case method: Text, cases, and readings*, 3rd ed.Boston, Massachusetts: Harvard Business School Press, 1994, pp. 34–68.