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Contributions

Diverging from the Dogma: A Call to Train Creative Thinkers in Science

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Science is creative

Science is an inherently creative process at each step, from synthesizing literature, identifying knowledge gaps, designing robust studies, to troubleshooting in the field (Osborne et al. 2003, Hadzigeorgiou et al. 2012). Creative thinking in the context of science has been defined in many ways, but we use Hadzigeorgiou et al.'s (2012) definition for the purposes of this piece – scientific creative thinking is an imaginative process that incorporates content-based knowledge to generate novel ideas. Divergent thinking, or the ability to generate multiple unique solutions to a problem and to connect disparate concepts in unique ways, is an inherent component of creative thinking, and is often considered the foundation of creative ability and complex problem solving (see Fig. 1; Guilford 1950, Wallach and Kogan 1965, Dym et al. 2005, Silvia et al. 2008, Shah et al. 2012). Further, divergent thinking is a catalyst of transformative science, since it encompasses the generation, adaptation, and evaluation of many novel ideas and solutions (Hadzigeorgiou et al. 2012, Shah et al. 2012). Convergent thinking differs from divergent thinking, in that it results in a correct or best answer, idea, or solution from a selective number of concepts (see Fig. 1; DeHaan 2009). The practice of science as a whole is an iterative process involving trial and error, and at each step of project development, execution, and analysis, some *combination* of convergent and divergent thinking is required to arrive at a tenable and high-quality solution (DeHaan 2009). New directions in science are grounded in accumulated knowledge, using largely convergent principles (Boden 2001, Hadzigeorgiou et al. 2012), but brainstorming and project development hinge upon generative processes wherein divergent thinking is exercised (DeHaan 2009).

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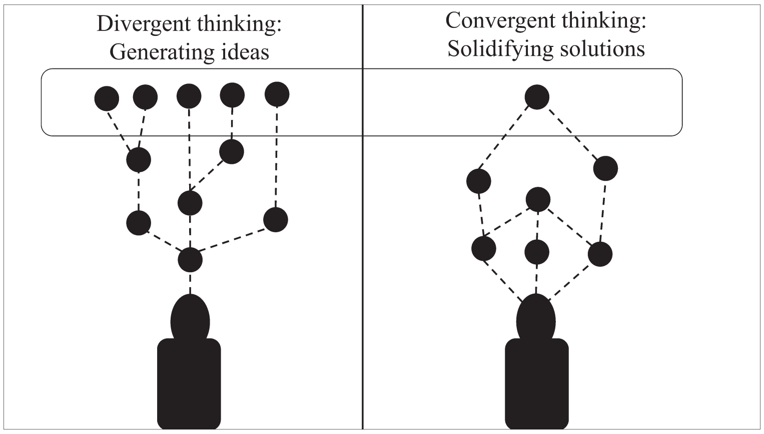

Fig. 1. Depiction of divergent (left) and convergent (right) thinking processes. A scientist generates many new ideas (black circles) through divergent thinking, arriving at multiple possible solutions. Alternatively, through convergent thinking, a scientist takes many facts or perspectives and arrives at a single solution. The black box contrasts the final outcomes of divergent and convergent thinking. We propose that scientists require both some degree of divergent and convergent thinking at every step of the scientific process to produce meaningful, thoughtful work.

As products of R1 universities and liberal arts schools, we feel that the current state of undergraduate STEM education does not accurately represent the frequent use of divergent thinking in science, in that science is often presented as inordinately rigid, memorization-based, and lacking creativity (DeHaan 2009). As graduate students at an R1 university, we challenge this narrative since we find that creative processes drive a large part of our routine work, and because, at a larger scale, scientific creative thinking has allowed for some of our greatest scientific advances that benefit society.

Our experience as graduate students

We come from a variety of undergraduate institutions with varying education models, ranging from progressive liberal arts colleges to larger R1 universities, and thus are uniquely poised to discuss shortcomings in undergraduate STEM education when preparing students for graduate programs. Despite this breadth of exposure to a spectrum of teaching techniques, every one of us has felt unprepared for some of the most common divergent thinking tasks encountered in graduate school, including: experimental design, adapting protocols, analyzing data, and writing manuscript discussion sections (Fig. 2). Conversely, across the board, all of us felt well-prepared for convergent thinking tasks such as reading manuscripts and textbooks, taking notes, completing projects and assignments, interpreting graphs, and following protocols.

Our undergraduate education trained us to successfully perform convergent thinking tasks, but outside of taking classes, these tasks are rarely needed in our daily lives as graduate students and developing scientists. We feel that these consistencies in feeling unprepared to undertake divergent thinking tasks in graduate school highlight the overwhelming gap between how science is taught in undergraduate STEM education and the realities of science as a complex, iterative, and creative process.

A main goal of graduate school is to transform incoming students who have been taught to predominantly digest others' scientific works into contributing members of the scientific community who create

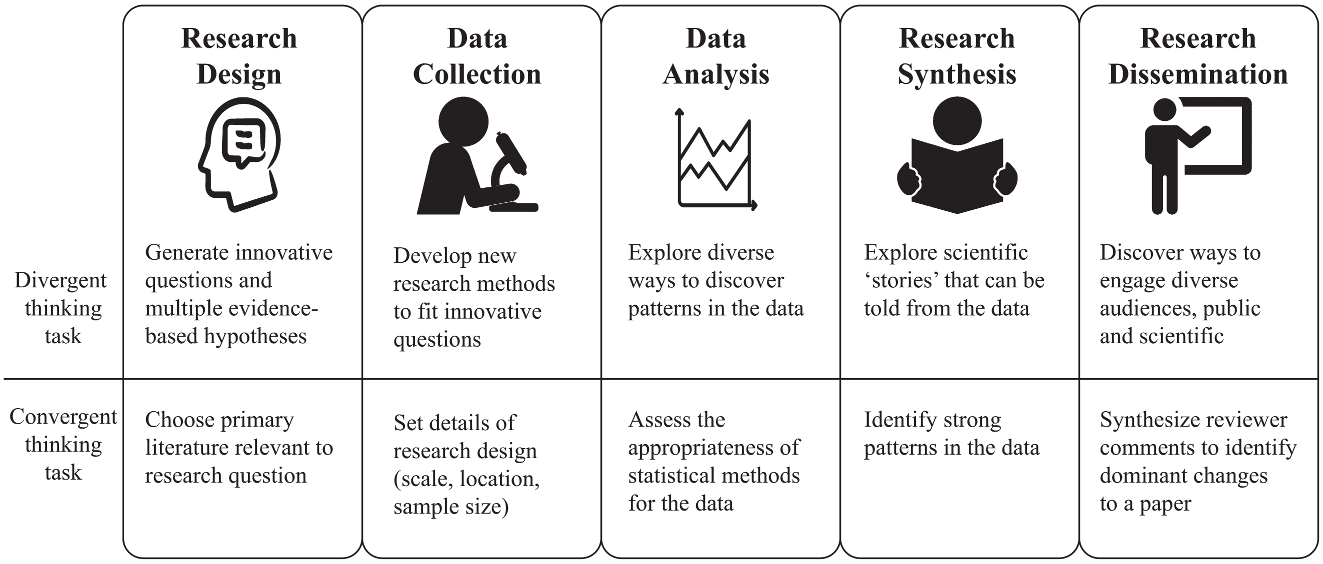

Fig. 2. Examples of research tasks at each stage of the scientific process that, from the authors' perspectives, involve primarily divergent or convergent thinking. We hope to illustrate the integral role of divergent thinking in the scientific process, and the need to learn and practice creativity skills to effectively perform scientific research. Icons (left to right) from the Noun Project, by Gregor Cresnar, beatriu.e, Path Lord, Creative Stall, and an anonymous artist from the Noun Project, respectively.

novel and insightful projects. To successfully generate meaningful scientific contributions, graduate students must develop astute research questions, effectively synthesize knowledge gaps from vast literature searches, design experiments, evaluate and revise data collection, correctly analyze and interpret output, and succinctly convey findings and their significance. Each of these steps involve divergent thinking (Fig. 2). As early-career graduate students, we found that the creative skills required of us were the most challenging to acquire in the transition out of our undergraduate years. In particular, we feel that divergent thinking, an avenue of creativity which requires the ability to generate multiple potential solutions to a problem, is a skill that graduate students are not explicitly trained in coming out of undergraduate science programs (Çimer 2012, Waldrop 2015). Without this training, we have observed that graduate students must spend much of their time independently developing their divergent thinking skills, distracting from their ability to produce novel research. In this era of the improvement of STEM education (AAAS 2011), we feel that this is an important and feasible gap in graduate training to address.

Active research on best practices in teaching scientific creativity

Recently, STEM education has transformed across the country; the implementation of active learning strategies, inquiry and research-based learning and other new innovations in STEM teaching and learning are sweeping through higher education. Calls have emphasized the need for the next generation of scientists to be trained in the practices of scientists and to be able not only to know what scientists know, but to *do* what scientists *do* (AAAS 2011). This emphasis on authentic scientific performance is also an implicit call for more training in creativity, since it is central to science. Thus, facilitating students' development of scientific creativity should be a priority in designing curricula and in promoting scientific career trajectories. Specifically, the discrepancy between how much convergent vs. divergent thinking is required in undergraduate vs. graduate education is a critical consideration in designing undergraduate curricula and in training new graduate students, who may not have formal training in scientific creativity.

Research suggests that creative, divergent thinking is a learned skill (Scott et al. 2004). Where traditional methods of education have focused on lecture-based teaching and convergent thinking, science education researchers are working to understand and implement best practices in teaching evidence-based reasoning and higher-order problem-solving cognitive skills (DeHaan 2009). Often, these practices include group problem-solving, personal response systems such as clickers, or course-based undergraduate research experiences (CUREs; Szteinberg and Weaver 2013, Auchincloss-Corwin et al. 2014, Freeman et al. 2014, Staub et al. 2016), which are designed to increase student engagement and encourage discovery and ownership over material. Going beyond changes in undergraduate curricula, we feel it is important that graduate programs provide opportunities for students to grow their divergent thinking skills upon entry. Below are four exercises that we have found useful as new graduate students in practicing divergent thinking. It is our hope that both individual graduate students and graduate programs alike can use these ideas as a template to develop a structured way of fostering divergent thinking skills in a research setting. However, we note that these four exercises are not comprehensive recommendations; a growing body of literature points to other practices, such as group collaboration and intellectual risk-taking, as promoters of creativity (Sternberg and Williams 1996, Paulus 2001, DeHaan 2009).

1. Judgement-free zone: Give your ideas space

Thinking creatively inherently involves taking some risks and thinking “outside the box.” Allowing yourself to explore new ideas will also lead to some non-starters, but resist the temptation to stifle your creativity by passing judgement on your ideas. Karban et al. (2014) describe a process for iterative thinking that can help you do this. First, identify a question to use as a starting place, such as “What is my research question?” Next, respond to that question by writing whatever pops into your head. Write continuously and without judgement for 10 minutes. At the end of those 10 minutes, highlight some phrases or ideas that you find appealing, transfer them to another document, and repeat the process. You can do this iterative process as many times as you like, and research suggests that the more ideas you generate, the more likely you are to come up with a novel idea (Kudrowitz and Dippo 2013). After you have finished, you can go back and critique your ideas, and hopefully you will have pushed yourself to think in some innovative ways that successfully tackle your question or challenge.

2. Change how you approach your research questions

In the age of the internet, it is easy to get stuck on endless Google Scholar searches, whether it is to see how other researchers have conceptually treated a research question or to explore methodological approaches. Or worse, a lengthy Google Scholar search session may convince you to treat a research question as though it has been completely “answered” and discourage further critical and creative thinking on the subject. Thus, these searches can often derail you from generating your own ideas and thinking critically about the robustness or novelty of your question and/or approach. Instead, “treat a task as a problem for which one invents an answer, rather than finding one out there in a book or on the blackboard” (Bruner 1965). We recommend practicing Exercise 1, and then utilizing Google Scholar *in moderation* while brainstorming. This will promote divergent and critical thinking, while also allowing you to situate your research within a larger context of known and unknown scientific knowledge. In addition, creating concept maps, which entails assembling concepts (and in a scientific context, this includes scientific knowledge) and defining relationships between separate ideas to create an organized network, could also be useful to encouraging ideational fluency in this exercise. Concept mapping can encourage cognitive gains by requiring you to fully understand separate concepts, as well as analyze and synthesize a network that enables identification of shortcomings or misconceptions in a given area of research (Safdar et al. 2012).

3. Step out of your comfort zone: Draw inspiration from outside your field

Applying methods or concepts from different fields or even related sub-disciplines can bring a fresh perspective to your scientific approach. Whether you hear something interesting on the radio or get an idea from a presentation at a conference, many creative ideas come from cross-fertilization. Always be on the lookout for ideas you could incorporate into your study system and actively explore new areas that you think might be useful. For example, biomimicry, the design and production of materials, structures, and systems that are modeled on biological entities and processes, is a great example of cross-fertilizing principles of engineering with knowledge from biology.

4. Question the assumptions of your field

This may seem obvious, but we believe it is actually more difficult than it sounds. As scientists, we encounter assumptions on a daily basis. Taking the time to identify those assumptions and then question their validity can lead to scientific breakthroughs. For example, many of us learned that early successional ecosystems are nitrogen limited, and later successional ecosystems become phosphorus limited. This paradigm was based on robust ecological studies; however, those studies were limited to humid coastal and island ecosystems. Questioning the assumption of nitrogen limitation in early successional ecosystems might not appear to be a useful or groundbreaking exercise at first, but that is exactly what a group of biogeochemists did. Their findings suggest that phosphorus, not nitrogen, is limiting in the early-successional systems they studied in the Canadian and Colorado Rockies, as well as the Peruvian Andes (Darcy et al. 2018).

Conclusion

Scientists generate many hypotheses to describe the world around them, and as new scientists, we need training in generating divergent and potentially groundbreaking ideas. Rather than viewing creative research as unique and unattainable, we postulate that all of us can learn to do great science by strengthening our divergent thinking abilities. As new graduate students, we aspire to do this kind of creative, transformative science. But overwhelmingly, undergraduate science education emphasizes convergent thinking tasks, and our ability to think divergently gradually atrophies under the assumption that creativity cannot be taught.

Here, we sought to use our experience as students that have recently transitioned into graduate school to highlight the need for explicit training in divergent thinking skills. We believe that this should be incorporated into undergraduate education, but that graduate programs can also foster these skills in mentorships, courses, workshops, and seminars. We look forward to new evidence-based approaches from education research that promote scientific divergent thinking skills that will train the next generation of boundary-breaking, paradigm-shifting scientists.

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Literature Cited

American Association for the Advancement of Science (AAAS). 2011. Vision and change in undergraduate biology education. AAAS, Washington, D.C., USA.

Auchincloss-Corwin, L., et al. 2014. Assessment of course-based undergraduate research experiences: A meeting report. CBE—Life Sciences Education 13:29–40.

Boden, M. A. 2001. Creativity and knowledge. Pages 95–102 *in* A. Craft, B. Jeffrey, and M. Leibling, editors. Creativity in education. Continuum, London, UK.

Bruner, J. S. 1965. The growth of mind. American Psychological Association, Washington, D.C., USA.

Çimer, A. 2012. What makes biology learning difficult and effective: Students' views. Educational Research and Reviews 7:61–71.

Darcy, J. L., S. K. Schmidt, J. E. Knelman, C. C. Cleveland, S. C. Castle, and D. R. Nemergut. 2018. Phosphorus, not nitrogen, limits plants and microbial primary producers following glacial retreat. Science Advances 4:1–7.

DeHaan, R. L. 2009. Teaching creativity and inventive problem solving in science. CBE—Life Sciences Education 8:172–181.

Dym, C. L., A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer. 2005. Engineering design thinking, teaching, and learning. Journal of Engineering Education 94:103–120.

Freeman, S., S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth. 2014. Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences 111:8410–8415.

Guilford, J. P. 1950. Creativity. American Psychologist 5:444–454.

Hadzigeorgiou, Y., P. Fokialis, and M. Kabouropoulou. 2012. Thinking about creativity in science education. Creative Education 03:603–611.

Karban, R., M. Huntzinger, and I. S. Pearse. 2014. How to do ecology. Second edition. Princeton University Press, Princeton, New Jersey, USA.

Kudrowitz, B., and C. Dippo. 2013. Getting to the novel ideas: Exploring the alternative uses test of divergent thinking. *In* 25th International Conference on Design Theory and Methodology; ASME 2013 Power Transmission and Gearing Conference (Vol. 5). American Society of Mechanical Engineers, New York, New York, USA.

Osborne, J., S. Collins, M. Ratcliffe, R. Millar, and R. Duschl. 2003. What "ideas-about-science"; should be taught in school science? A Delphi study of the expert community. Journal of Research in Science Teaching 40:692–720.

Paulus, P. 2001. Groups, teams, and creativity: the creative potential of idea-generating groups. Applied Psychology 49:237–262.

Safdar, M., A. Hussain, I. Shah, and Q. Rifat. 2012. Concept maps: An instructional tool to facilitate meaningful learning. European Journal of Educational Research 1:55–64.
Scott, G., L. E. Leritz, and M. D. Mumford. 2004. The effectiveness of creativity training: A quantitative review. Creativity Research Journal 16:361–388.
Shah, J. J., J. Woodward, and S. M. Smith. 2012. Applied tests of design skills—part I: divergent thinking. Journal of Mechanical Design 134:021005-1–021005-10.
Silvia, P. J., B. P. Winterstein, J. T. Willse, C. M. Barona, J. T. Cram, K. I. Hess, J. L. Martinez, and C. A. Richard. 2008. Assessing creativity with divergent thinking tasks: exploring the reliability and validity of new subjective scoring methods. Psychology of Aesthetics, Creativity, and the Arts 2:68–85.
Staub, N., et al. 2016. Course-based science research promotes learning in diverse students at diverse institutions. Council on Undergraduate Research Quarterly 37:36–46.
Sternberg, R. J., and W. M. Williams. 1996. Learning basic techniques. Pages 11–19 *in* N. Modrak and D. Simpson, editors. How to develop student creativity. Association for Supervision and Curriculum Development, Alexandria, Virginia, USA.
Szteinberg, G. A., and G. C. Weaver. 2013. Participants' reflections two and three years after an introductory chemistry course-embedded research experience. Chemistry Education Research and Practice 14:23–35.
Waldrop, M. M. 2015. The science of teaching science. Nature 523:272–274.
Wallach, M. A., and N. Kogan. 1965. Modes of thinking in young children: a study of the creativity intelligence distinction. Holt, Rinehart and Winston, New York, New York, USA.