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The Pursuit of Transdisciplinary Research

Eight Recommendations for Integrating Disciplines

Significant strides are being made to produce more transdisciplinary research in the systems, man, and cybernetics (SMC) community, which is inherently interdisciplinary. To produce effective transdisciplinary SMC work, perspectives from multiple disciplines must be integrated. Yet, continued work is still needed to help promote the transdisciplinary nature of SMC and encourage more transdisciplinary work in this area. This article offers eight recommendations for developing foundational transdisciplinary SMC-based research. These recommendations relate to the following areas: 1) academic training, 2) a shared and common language, 3) the need for transdisciplinarity, 4) problem space requirements, 5) shared spaces and mechanisms, 6) team science and cognition, 7) credit, and 8) metrics to measure transdisciplinary performance.

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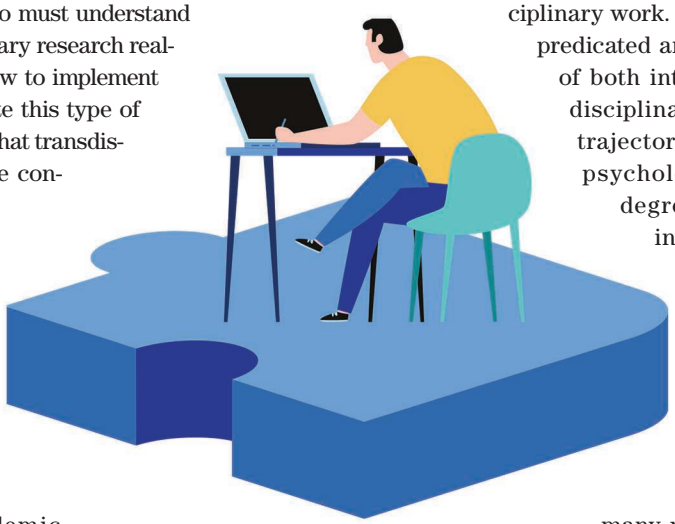
The Importance of Interdisciplinary Work

Transdisciplinary, *interdisciplinary*, and *multidisciplinary* are terms that permeate discussions in many scientific communities. These concepts are often interchangeable and have, unfortunately, become buzzwords in various sectors to indicate positive attributes. Many have heard the praises of both interdisciplinary and transdisciplinary work. In 2015, the scientific journal *Nature* published an entire special issue devoted solely to the importance of interdisciplinary work [1]. The important question is: Why is it so critical to generate this type of work?

This work comes to fruition through multiple perspectives applied together to solve major societal problems. These unique perspectives allow for multidimensional problem solving that would otherwise be difficult if approached via only one discipline. Even with these perceived benefits, opportunities to engage in this type of work are often missed. Simply, interdisciplinary and transdisciplinary work is hard, a fact that this article underscores. Bringing people together from differing backgrounds requires give and take from each entity, and people must proactively cooperate to produce this work. Yet, moving forward, it will be fundamental to improve science and produce more inclusive findings.

The SMC community should continue to implement both interdisciplinary and transdisciplinary work, while specifically striving to produce more transdisciplinary research. Yet, to do so, we also must understand and define what transdisciplinary research really is, and we need to grasp how to implement methods to effectively generate this type of work. Thus, I aim to identify what transdisciplinary work is and provide concrete recommendations for how to approach this type of research. The recommendations provided in this article are essential for making our community more transdisciplinary.



By definition, *interdisciplinary* means to involve "two or more academic, scientific, or artistic disciplines" [2]. Therefore, SMC clearly fits into the parameters of this definition. SMC, at its core, brings together many domains of science and research to produce innovative work only available at the intersections of different domains [3]. The SMC community includes a wide variety of expertise: computer scientists, electrical engineers, industrial engineers, psychologists, sociologists, and professionals from many other disciplines. This is fantastic news for the pursuit of transdisciplinarity. Essentially, it means that our community already has the building blocks for creating transdisciplinary work. But this type of work requires more than these building blocks. There needs to be an architecture, a game plan, and a script (whatever you may call it) to organize those interdisciplinary blocks in a meaningful transdisciplinary manner. My hope is that some of the recommendations presented here will help in that effort.

While SMC is inherently interdisciplinary, it is not inherently transdisciplinary. Proactive work is required to move from interdisciplinary to transdisciplinary. Interestingly, when looking up *transdisciplinary* in the dictionary, it refers back to *interdisciplinary* without a true definition. So what really does *transdisciplinary* mean?

The varied makeup of SMC that results in our community being interdisciplinary does not inherently result in transdisciplinary work. The process of becoming transdisciplinary is the natural evolution of activating interdisciplinary knowledge and methods. Interdisciplinary units must work together with specific aims and goals to then achieve transdisciplinary work. Transdisciplinary work is the addition and multiplication of interdisciplinarity to create and generate new innovative thoughts, products, and, generically speaking, research.

The addition and multiplication are the hard part. If I look back on my career, this is where I have needed guidance, and much of that guidance was generated via failure in attempting to attain widely transdisciplinary work. My entire career has been predicated and based on the principles of both interdisciplinary and transdisciplinary work. My educational trajectory began with a degree in psychology. Then I obtained a degree in the foundationally interdisciplinary domain of information science and technology. I conducted postdoctoral research in human factors, and I am currently a professor in computer science (human-centered computing). Down these many paths, I have experienced various successes and failures, which have taught me many lessons about how to conduct transdisciplinary work. I am certainly not suggesting that I have any of the answers. But I do have recommendations based on what I have learned throughout the process. These recommendations do not represent a perfect path toward conducting this type of work, but I hope they provide insights that better enable readers to advance from being in a single domain to performing interdisciplinary work. I further hope these thoughts lead you to define and create transdisciplinary work from your own perspectives.

Foundational Recommendations for Transdisciplinary SMC Research

The following eight recommendations are foundational to ensuring that SMC sustainably promotes transdisciplinary work (Table 1). Almost all of these recommendations stem from my own experiences. They are not meant to be exhaustive. During the preparation of this article, many more were generated, but these are viewed as the most critical.

> The interdisciplinary training of future SMC scientists is not a want but a need.

Academic Training

There is a reason for presenting academic training first. Simply, the question of how we train the next generation of scientists should be our starting point. More specifically, we need more scientists whose educational training is interdisciplinary to begin with. This means that we need more people who specifically study one area for one degree and then study another area for their next degree, and more people who seek out specific degree programs that are interdisciplinary are also imperative. In recent years, there has been a push to create more of these interdisciplinary educational degrees, but there is a severe need for more (for additional information on new models of academic training, see [4] and [5]; and for a historical review of these types of programs, see [6]). There is something to be said about someone who is trained on interdisciplinary content and taught to think about problems in a transdisciplinary manner. In some ways, this training lowers the barrier for entry into transdisciplinary work because it allows transdisciplinary cognition to become second nature.

The interdisciplinary training of future SMC scientists is not a want but a need. The work conducted in this community often requires a working knowledge about multiple domains of a particular problem. A researcher could certainly collaborate with others who have different expertise, but there will be issues that stem from that. Instead, having someone who was formally trained to possess expertise in multiple areas will most likely lessen the overhead often required for collaboration. Take, for example, high level, human–computer interaction. Only having knowledge pertaining to the human/social aspects without a working knowledge of associated technology is not enough. Failing to understand the back end of a piece of software will lead to inadequately designing a humancentric front end due to lack of knowledge pertaining to the limitations or challenges of the back end. Scholars do not have to be experts in both, but there is value in having a working knowledge of each aspect.

In general, we need leaders in the SMC community to promote the importance of interdisciplinary academic training. For the most part, we must move away from

Table 1. Eight foundational recommendations for transdisciplinary SMC research.

Recommendation	High-Level Description
Academic training	Students need to be trained from an early age to think from the perspective of multiple disciplines, and more specific programs must be developed that seek to do this at all educational levels.
A shared and common language	A shared and common language is necessary for transdisciplinary work to be successful. People must seek out a shared word repository that is used across scientific domains.
The actual need for transdisciplinarity	Not all scientific work is transdisciplinary. There has to be a root cause shared among disciplines to put together an interdisciplinary team and study a topic in a transdisciplinary manner.
Problem space requirements	The scientific problem at hand dictates whether it is transdisciplinary, and that problem must be looked at in detail to identify this issue.
Shared spaces and mechanisms	Transdisciplinary work should allow people to interact in a shared manner. Interaction is at the core of making transdisciplinary work successful, and spaces need to be developed that allow for this interaction.
Team science and cognition	Transdisciplinary work requires an understanding of both team science and team cognition.
Credit	Better methods are required to acknowledge and provide credit to people (both in academia and industry) working on transdisciplinary projects.
Metrics to measure transdisciplinary performance	Improved metrics are needed to evaluate the performance of those who work in transdisciplinary projects.

siloed learning and thinking if we are to transform SMC into an exemplar of transdisciplinarity. This is not to say that everyone should be trained in this manner. There is, and always will be, significant value in scientists who have degrees in only one domain and have extremely deep knowledge in that one area. This argument is twofold: 1) we need to increase the number of scientists who are trained in a diverse manner with both knowledge of breadth and depth, and 2) scientists who are being trained in a single domain (without an interdisciplinary focus) must, at a minimum, have an understanding and consideration of different perspectives.

A Shared and Common Language

Transdisciplinary research is often riddled with language and communication problems. A recent National Academies of Science study focused on the area of team science highlighted the challenges associated with this type of work [7]. Due to most transdisciplinary research occurring via groups of scientists trained in different domains, each domain has a very specific language associated with it. A favorite example of this that continually rears its ugly head is the use of the word *model*. To social scientist colleagues, a model often refers to a theoretical framework that explains a social behavior at an individual, group, or societal level. Yet, to computationally focused colleagues, a model is different, often alluding to a mathematical model requiring computation to explain a technical system. The use of this word usually plays out in the following way: both sides will be using the word *model*, and over time, they will both figure out that they are referring to different things, which then necessities a conversation where each side defines what they mean. This also often results in the group revisiting their previous conversation with the realization that they were discussing fundamentally different things. This process is not overly productive or efficient, but it is one that routinely happens repeatedly in transdisciplinary efforts.

Transdisciplinary research is often riddled with language and communication problems.

The question becomes, how do we avoid these misunderstandings? The answer is simple but difficult to implement without creating a shared catalog of scientific words. At the beginning of any transdisciplinary collaboration, the team should attempt to produce a shared word repository. Scientists from each domain should think about common words they use and define them for the larger group. This is not a catchall, and there will still be many words that are confused, but it goes a long way toward alleviating common linguistic misinterpretations. In addition, people should be aware that they are working with people from different domains, and they should strive to overcommunicate. This means going the extra mile to specifically explain what is being communicated. Language used in one community, while useful and logical in that community (based on academic training), may not make sense to colleagues in other communities (who have different academic training).

The Actual Need for Transdisciplinarity

Not all research should or needs to be transdisciplinary. As modern scientists, we often get caught up in the pursuit of transdisciplinarity when it is not needed. More transdisciplinary research is a good thing, but we must be aware that many problems do not require it (more on this in the next section). Often, we see a call for a grant that requires a diverse team, or we know that our team will be looked at more favorably if we have an interdisciplinary team. But recent research shows that it is easier to acquire grant funding from a single-domain perspective than one that is interdisciplinary [8]. Being transdisciplinary for the sole purpose of being transdisciplinary does not necessarily mean you will be better aligned to acquire funding or, more importantly, to push the needle of science in the right direction. There has to be a root cause shared among disciplines to put together an interdisciplinary team and to study something in a transdisciplinary manner.

Many research projects require investigation that involves a team of scientists across a diversity of disciplines. Yet, there are many that do not, and research teams still seek out different team members for the wrong reasons. Devising an interdisciplinary team for purposes outside of the scientific aspects of the project is foolhardy and also waters down the potential impact that real transdisciplinary research can deliver. Simply put, transdisciplinarity is needed when the science calls for it. Scientists and researchers should be cautionary and carefully examine what they want to study and then systematically determine whether multiple perspectives from different domains bring something to the table.

Problem Space Requirements

One way to evaluate whether science needs transdisciplinarity is to focus on the problem. The scientific problem typically dictates and lends itself to discovering whether there is a need for a set of diverse scientific perspectives. As previously noted, there is not always a need for multiple perspectives. Yet, increasingly often, this type of work is required. In general, problems are not getting simpler. Many large scientific problems are currently grounded within multiple scientific systems. An easy example of this type of problem space is climate change. Climate change demands transdisciplinary work to fully understand the concept and potential impacts ([9], from 1977, calls for

interdisciplinary approaches to climate change). Experts ranging from earth scientists, chemists, biologists, civil engineers, industrial engineers, to computer scientists represent just a few of the many domains that must be tapped to tackle such a complex problem.

When considering whether a problem is inherently transdisciplinary, it is useful to analyze it both locally and globally to understand the potential diversity associated with that problem. Local analysis is the easier of the two and simply requires the examination of the problem from the perspective to which it is most closely aligned. Revisiting climate change as an example, a local analysis requires looking at it from the perspective of earth science (its most dominant domain). The need for transdisciplinary work may stem from this local analysis, depending on how varied the dominant perspective.

Global analysis requires more creative, outside-the-box thinking. I like to think of most large challenges as systems-integration problems, because they are grounded in many different systems at once, and a perturbation to one system may directly or indirectly drastically impact another system. So, with global analysis, you need to think about all of the associated systems/domains that are both directly and indirectly linked to your problem. Depending on the complexity of the problem, it may very well be paramount to bring in experts from these systems to provide a wholistic understanding of the problem.

> **Not all research should or needs to be transdisciplinary.**

Shared Spaces and Mechanisms

The nature of transdisciplinary work often requires scientists in different places to work together. As we know, distributed work can be challenging for a multitude of reasons. Colleagues should take a look at the computer-supported cooperative work community for an overview of the pain points associated with distributed work [10]. More specifically, there is an SMC technical committee on computer-supported cooperative work in design that is helpful in learning more about this community. In general, the best approach to alleviating this problem is setting forth a work plan from the beginning of the transdisciplinary project.

A work plan should clearly articulate how work will be completed and shared among various members of the team. A platform of information communication technology needs to be chosen, and the overall team must agree and buy into the notion of only using that platform. Is digital communication going to be facilitated via email or a platform like Slack? What file-sharing platform will be used? What audio/video-teleconferencing platform will be selected, and who will lead associated meetings? These may seem like unimportant questions, but if they are not decided at the onset of work, then distribution becomes very muddied and transdisciplinary work becomes even more difficult.

Team Science and Cognition

Most of the recommendations here are grounded in the areas of team science and team cognition. Team science is a relatively new domain of research that specifically focuses on studying how large interdisciplinary teams of scientists work together. The aforementioned National Academies of Science study is a fundamental resource to improving transdisciplinary work. Moving forward, more empirical research is required to further understand the challenges faced by large science teams. This research will then inform transdisciplinary work.

Team cognition is needed to improve team science and transdisciplinary work. Team cognition is the cognitive activity that takes place at the team level and often results in a shared understanding of both teamwork and taskwork. It is often viewed from a macrocognitive perspective where the focus is on how cognition occurs in natural environments [11]. The concept of team cognition is well founded in multiple scientific communities and is most often associated with the concept of a team mental model [12].

Transdisciplinary teams need team cognition. The composition of a transdisciplinary team by definition requires different perspectives. Therefore, these teams start out working with very different individual cognition and, to develop a shared understanding of the varied cognition on the team, they must communicate and share their individual cognition. If these transdisciplinary teams fail to develop common ground or have a shared understanding, it makes problem solving and working together very difficult. In sum, transdisciplinary teams must proactively work together (through communication) early on in the work process to develop team cognition.

Credit

Who gets credit for what in a transdisciplinary team? This is not an easy question to answer, and this article will not attempt to provide an answer. Both academia and industry should better support and provide work credit to transdisciplinary team members. Regardless of the context, whether in industry or academia, people want to be acknowledged for the work they have conducted and given credit. From an institutional perspective, there must be an understanding that there is a give and take that occurs during transdisciplinary teamwork. For example, not all team members will be able to always publish in their concentration, and institutions need to be sensitive to that. Speaking directly to academia, if there is going to

continue to be a push for transdisciplinary work (and there should be), then higher education needs to better define a path for fair and consistent criteria for evaluating transdisciplinary participants. Additional information relating to academic credit in relation to transdisciplinary work can be found in [13] and [14].

Metrics to Measure Transdisciplinary Performance

Finally, and in relation to the previous recommendation, better metrics to measure transdisciplinary work are needed. It is easier to measure perceived impact and success of single-domain work. Typically, publications, protocols, policies, and patents are released to highly respected historical domain-specific outlets. But what happens when those same outlets do not fit the needs of transdisciplinary work? We must develop new innovative methods to define what success is within transdisciplinary work. Progress is slowly being made in this effort with the advent of transdisciplinary journals and conferences. In addition, we have seen efforts put forth with the goal of creating actual performance metrics that include informetrics and innovative citation counts [15]–[17]. Yet, more must be done, and it starts with more empirical work being conducted to study real transdisciplinary teams working in context. This work will help define good and bad transdisciplinary performance.

Conclusion

SMC has the ability to become a community leader in advancing transdisciplinary work. All of the necessary pieces to producing transdisciplinary work are currently available within the community. SMC has greatly helped me in developing and positioning my own transdisciplinary work on human–machine teaming [18], and this gives me a great deal of hope moving forward.

But we must work together as a community to define and develop procedures that push us to produce transdisciplinary work. Being inherently interdisciplinary does not make us transdisciplinary. Transdisciplinary work requires additional proactive and focused work toward the goal of being transdisciplinary.

About the Author

Nathan J. McNeese (mcneese@clemson.edu) earned his B.S. degree in psychology and his Ph.D. degree in information sciences and technology, both from The Pennsylvania State University, State College, in 2009 and 2014, respectively. He is an assistant professor and director with the Team Research Analytics in Computational Environments Research Group within the Division of Human-Centered Computing in the School of Computing at Clemson University. He also holds a secondary appointment in Clemson's Human Factors Institute, is a faculty scholar in Clemson's School of Health Research, and is a Watt Family faculty fellow. His current research interests include human-agent teaming, human-centered collaborative tools and systems, and human-centered artificial intelligence. He serves on multiple international/societal program and technical committees, in addition to multiple editorial boards including that of *Human Factors*. He is a Member of the IEEE.

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