

What is Convergence?: A systematic review of the definition of and aspects of convergent work

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Abstract—Wicked problems, the National Academy of Engineering's Grand Challenges, the United Nations' Sustainability Goals, and similar complex, global-scale endeavors fall under the broad umbrella of “convergent” work. Over the past two decades there has been an increase in interest and funding for work in this space. The NSF has two programs focused in this area, *Growing Convergence Research* and the *Convergence Accelerator*. Boston University's College of Engineering recently announced a focus on convergent projects and work. The National Academic of Engineering also has the Grand Challenge Scholars program with over 100 participating schools. The list continues to grow. The broad concept of convergence seems to be quite simple: combine the ideas, skills, and/or methods of multiple disciplines to create something new. More specific definitions vary and while the interest in convergence and convergent problems continues to increase, there is no easily operational definition of convergence. This is especially true with respect to undergraduate-level education where students have limited experience and knowledge to carry out such efforts.

To better understand the variation that exists within the literature on convergence we conducted a systematic review to explore how convergence is defined in scholarly literature. We have identified a small number of categories within the definition space and conducted a thematic analysis of the aspects of each. The results show that there is a fairly consistent focus on the work being socially-relevant and on creating something new such as an idea, method, product, or process to address desired needs. Additionally, doing convergent work requires the integration of aspects of multiple disciplines and is conducted by diverse teams. Lastly, the disciplinary backgrounds of those teams almost always includes the natural and biological sciences with a subset the following disciplines: information or computing sciences, engineering, social sciences, and humanities. While there is some consistency in the definition, there also seems to be space for some variation which leaves for some level of choice in the definition.

Index Terms—convergence, complexity, systems engineering, grand challenges, transdisciplinary

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I. INTRODUCTION

The word “convergence”¹ has multiple definitions depending on the context of its use. The definition contexts include general use, math, biology, physics, ophthalmology, meteorology, and technology [1], [2]. While the last of those is the closest to our area of interest it is not broad enough for our desired use. For this paper, we are interested in what convergence means within the context of creation and/or addressing problems that combine different ideas, methods, or approaches. The term has been adopted by the National Science Foundation (NSF) in the United States and the Korean Research Foundation in Korea in the context of research as an appropriate approach to address important problems in a non-traditional manner.

Our particular focus of this paper is to operationalize the term by exploring the bounds of this term within the space of convergent work. We analyzed some of the various aspects of work that is self-labeled “convergence” seeking to understand the consistent and varying aspects of it.

The larger goal of our work is to prepare undergraduate students to do convergent work following graduation. Our first step in doing this is to understand the space of convergence which we equate to reviewing how it is used in the literature. Once we have an understanding of the aspects and themes of the definition, we can craft an operational definition that fits our context and begin to add aspects to our undergraduate engineering program in order to support student learning and development in this direction. While beyond the scope of this paper, this is the motivation for this work.

To explore this space, we conducted an initial systematic review of the literature using the OpenAlex database. We reviewed a collection of articles self-labeled as convergent work that defined convergence and explored the collective space of those definitions, identifying a small number of categories and identified themes within each. We further explored the

¹We use the terms convergence, convergent work, and similar terms interchangeably throughout this paper in reference to convergent problems, solutions, and approaches.

citations of this work to understand where these definitions originated to understand a bit of the history of the effort.

II. METHODS

Our systematic review is focused on answering the following two questions.

- 1) *What are the definitions of convergence?*
- 2) *What has informed these definitions?*

Our first step was to identify a list of articles that defined convergent work. We used the OpenAlex database [3] and evaluated multiple query options. Searching titles for the string “convergence research” produced a reasonable number of results and a relevant set of articles that focused on the desired definition. We observed that this query also searched other forms of the word convergence including converged, converging, convergent, and converge. We tried other queries including full-text search queries for the same term but these yielded either too many results to reasonable review (several thousand) or a large percentage of results that used a different contextual definition of the word convergence, typically convergence in math or economics. Searching titles for “convergence research” produced a set of approximately 200 papers.

We reviewed the initial set and selected papers that:

- 1) included a definition of convergence and
- 2) focused on the inclusion of multiple disciplines to create something.

The initial set of papers included over 80 articles written in Korean with English abstracts. The Korean national research agency has been supporting convergent work for over a decade. These abstracts were reviewed in the same way but none were selected because they did not contain a definition of convergence. They tended to focus on a particular project or application of convergence. Based on the abstracts we inferred that the definition of convergence in this context is the application of one discipline’s ideas in a different context but a specific definition was not found. Papers about convergent work that did not define convergence were not included. A final set of 18 papers was found to meet these criteria and they were analyzed for this paper.

We analyzed the definitions of convergence in these papers and identified a set of themes. For each theme we analyzed how those themes were included in the definition and in what way. We identified the following themes from this first pass: the desired outcomes of the work, specific aspects that must be included in the work, the disciplines involved or required to do convergent work, and the sources of the definitions of convergence. The full list and explanation of all of the themes is in Section IV. A second pass of the articles was conducted to more thoroughly analyze each work with respect to the set of themes to ensure that our analysis was consistent.

A. Limitations

A major limitation of this work is the challenge of finding work focused on the desired type of convergence because the

TABLE I
ORIGIN SOURCES OF CONVERGENCE IN ORDER OF FREQUENCY, EACH INDIVIDUAL SOURCE MAY CITE ONE OR MORE OF THESE ORIGIN SOURCES

Entity	Use Count
US National Academies reports [4]–[8]	5
NSF Website [9]	5
Roco and Bainbridge [10]–[12]	4
Sharp [13], [14]	3
European Conference Report [15]	1
Inst of medicine [4]	1

term “convergence” has multiple definitions. Differentiating between one type of convergence using text-based queries is challenging and it is amplified by the limited searching capabilities of OpenAlex. OpenAlex does have a variety of metadata about sources available to search. For example, each entry has a list of “concepts” associated with it. While “convergence” is actually one of those concepts the economic type of convergence is used. We found that it was applied to some of the entries we included in our review but it was not applied consistently. Additionally, we can only search for work that is self-identified as being convergent. While we realize the limitations of our approach, we believe the conducted review identifies a number of aspects of convergence based on our additional, preliminary ad hoc searching and article reading.

III. ORIGINS

To better understand the origins of the perspectives on convergence, we analyzed the roots of the definitions of convergence in the work we collected through the list of works cited. The results for this analysis are shown in Table I. The data shows that a majority of the definition of convergence came from US national entities like reports from National Academies and the NSF. It is worthwhile to note that two authors, Roco and Brainbridge, are/were both staff members of the NSF which means that a large majority of the ideas of what convergence is stems from a very small space. These two seem to be at the root of much of what has been done at the NSF. We also want to note that one source [13] is no longer accessible at its original link. We have some concern over this as the origins of ideas are important to understanding how ideas have come to be. There was also mention of a report from MIT in 2000 that we cannot locate.

These origins explain some aspects of the data in this paper. As noted, national research funding bodies want to grow research which matches the outcomes from the articles. Additionally, the term “convergence” and much of the work seems to originate from the NSF and the National Academies of Sciences, Engineering, and Medicine which focus on the natural sciences and engineering. This explains the strong tilt towards STEM in aspects of the definitions.

IV. RESULTS

This section contains data our thematic analysis including an introduction of each theme and further analysis of each.

TABLE II
THE PERCENTAGE OF DEFINITIONS OF CONVERGENCE THAT INCLUDE EACH OUTCOME

Outcome	Use	References
Socially relevant problems	79%	[12], [16]–[21]
Create commercializable tech	21%	[17], [18], [22]
Create fundamental work	59%	[12], [16], [17], [19], [22]–[28]
Create local solutions	14%	[12], [21]
Increase research productivity	21%	[17], [22], [26]

We identified the following list of *outcomes* based on the definitions of convergence.

- **Address massive, socially-relevant problems or challenges:** The work aims to improve the life of some subset of people. The problems are typically large enough to impact large groups of people and likely to cross international borders.
- **Create new commercializable technology:** The work is focused on creating a technology, processes, or services that can be marketed. This is in contrast to work that focuses on policy, methods, or other intangible outcomes.
- **Create new fundamental knowledge, typically in order to drive research onward:** The focus of the work is to create new domains, disciplines, or sub-disciplines. The field of nanotechnology is often given as an example of successful convergent work.
- **Create local solutions to local problems:** This goal is often paired with the goal of addressing large scale problems but with a focus on solutions that are not one-size-fits-all. This increases the challenge of the work because it requires a great deal of understanding of the global and many individual local contexts of the same problem.
- **Increase research productivity:** To move research faster or further likely through the creation of new methods, ideas, or approaches. This focuses on doing something *better* but not necessarily in a new field.

Table II shows the prevalence of each outcome in the set of articles. Each article identified one or more of the listed outcomes. Addressing socially-relevant problems and creating fundamental research work stand out among the set as the most common outcomes.

The next theme is aspects of the convergent process or the people doing the work. We identified the following aspects of this theme.

- **A focus on social justice:** The work has a focus on social justice, which we assume, impacts decision making along the way.
- **An integration across disciplines of theories, concepts, and approaches:** The work has aspects of transdisciplinarity [29].
- **The integration of Team Science:** The work specifically calls upon the methods and focus of the Science of Team Science [30].
- **Requires the work of a diverse team:** The definition explicitly calls for a team of individuals with diverse

TABLE III
THE PERCENTAGE OF DEFINITIONS OF THAT INCLUDE EACH ASPECT OF PROCESS OR PEOPLE

Element	Use	References
Social justice approach	14%	[21], [27]
Integration of disciplines	93%	[12], [17]–[28]
Integration of Team Science	29%	[20], [25], [27], [28]
Requires a diverse team	71%	[12], [17], [20], [21], [23]–[28]
Engages multiple sectors	29%	[12], [20], [21], [25]
Entrepreneurial aspects	7%	[26]

TABLE IV
THE DISCIPLINARITY REQUIRED OR EXPECTED TO DO CONVERGENT WORK.

Disciplinary Group	Use	References
All disciplines	14%	[12], [25]
Unclear	21%	[19], [20], [26]
Of the remaining:		
Info / Comp Sciences	49%	[16], [17]
Natural Sciences	89%	[16]–[18], [22]–[24], [27], [28]
Mathematics	44%	[16], [23], [27], [28]
Engineering	78%	[17], [18], [21], [23], [24], [27], [28]
Social Sciences	78%	[16], [18], [21]–[23], [27], [28]
Humanities	44%	[18], [22], [23], [27]

traits, experiences, and possibly broader aspects. The definition of diversity and clarity on the definition of diversity varied within the set of sources.

- **Engages multiple sectors:** Separate from discipline, the work involves multiple sectors including academia, government, private sector, non-profit stakeholders and so forth.
- **Has aspects of entrepreneurship:** The work explicitly calls upon entrepreneurship that may include commercialization, customer discovery, and manufacturability, for example.

The prevalence of each element is shown in Table III. The percentages in the table do not add up to 100 percent because each article could include multiple elements. The two dominant aspects of convergence work based on our data are the integration of disciplines and requiring a diverse team. This data supports our initial understanding of convergent work and it expands the space beyond our initial assumptions.

The third theme of the definition of convergence is the list of disciplines that are expected to be involved in the work. This expands on prevalence of multidisciplinarity found in the last theme. We identified the following disciplinary groups: information / computer / computational sciences; “natural science” which includes the natural and biological sciences; mathematics; engineering; social science; and humanities. Some works did not list specific disciplines but in some cases we could infer that the assumption was a broad set of disciplines and focus on including *all* disciplines or with a philosophy that more and broader is better.

Table IV shows the disciplinary groups for convergent work. Articles that defined that convergence work include all disciplines or for which it was unclear are shown in the top two rows of the table. For the rest of the articles, the disciplines

included in the definitions are marked. Articles included in the top two rows are not included in the counts of the lower rows and vice versa.

V. ANALYSIS

Our interest in this data is both the prominence of specific outcomes, elements, and disciplines *and* the breadth of definitions. We interpret the variation of the space here to reflect the ability for some choice in what can be done under the umbrella of the term “convergence”. Based on the data in our review we found some consistent and some variable aspects to the space of convergence. There is fairly consistent focus on addressing socially relevant problems and creating a foundation for future research, which is a key goal of funding agencies. There seems to be some focus on the creation of commercially viable technology (products, services, etc.) which we also interpret as a strong STEM focus in these outcomes which is apparent through the language, a focus on “problems and solutions”, as well as a focus on creating stuff. This is in contrast to other domains where policy and analysis might be more prevalent. Looking at these together, we conclude that there is a mix of research and application focus in this space.

Of the different aspects of convergent work, it is nearly universal that there is integration across disciplines. The exception to this is by an author who has later work that includes disciplinary integration so we assume that there was perspective change or too little information given in the first work. Additionally, the need to have a diverse team is prominent. We interpret this in the following way. First, that convergence *requires* a team and convergent work cannot be carried out by an individual. And secondly, that the team must have some aspects of diversity to it. Based on the disciplinary data we assume that at least portion of the definition of diversity includes disciplinary diversity. The breadth of the definition of diversity is, for the most part, unclear.

The perspective on the disciplines included in convergent work is somewhat varied. While the natural and biological sciences are nearly universal, the other disciplines appear greater than 50% of the time but they are not universal. In short, convergent work will have some aspects of natural science and some flavor from some other discipline which can vary. We are somewhat surprised by the constrained set of disciplines considered but note that medicine is a focus of some of the early reports on convergence. We explored this more in Section III.

Another item that arose as we analyzed these works was transdisciplinarity and how it is connected to convergence. Some authors used the terms transdisciplinary work and convergent work interchangeably while others typically elected to identify transdisciplinarity as a required aspect of convergent work. This variation makes sense as the term is defined in different ways. Rosenfield has a fairly minimal definition in [29] while Hirsch et al. have a much more complicated take on the term in [31].

Finally, some sources noted additional aspects of convergent work including support needed or challenges facing it.

Points included were challenges in funding [18], [22], [27], building connections across disciplines or groups [18], [27], [28], training researchers [27], [28], and evaluating convergent work [18], [22], [28].

VI. CONCLUDING THOUGHTS AND FUTURE WORK

Based on the space explored for this paper, it seems that there is a shared core definition of convergence but there are also some variable aspects to it beyond the core. Much of its origin is from U.S.’s national research leaders. The space of convergence is more than just integrating across disciplines and it also dictates the types of problems being addressed, specifically large-scale, complex socially-relevant problems. A transdisciplinary approach is common which includes at least a subset of the STEM disciplines as well as social sciences and the humanities. Some sources suggest that it is broader than this as well. We intend to spend additional time to explore more queries to get a broader sense of the use of the term convergence and will attempt to identify other words or phrases with a similar meaning that are used in other contexts. We also want to explore what the Korean research agency means by convergence.

Our next step is to focus in on our group’s definition of convergence and how we can begin to prepare undergraduate students to go work on convergent problems in the future. We plan to create a breakdown of convergent work with a focus on the various aspects that we wish for students to develop and identify the ways in which individuals need to develop and teams need to develop. How we support and evaluate these areas will be needed as well.

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