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Collaborating Toward Convergence Efforts for K-20 STEM Education

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Abstract

The paper examines the use of NSF's Collaborative Infrastructure and the Convergence Research approach for complex social innovation challenges used by the authors in their NSF INCLUDES project (#1744490). The paper clarified terminologies related to Convergence Research for multi-, co- inter- and trans-disciplinary. This paper defines and describe collaborative research at each of these interfaces. Then it discussed key factors for engaging in collaborative partnerships as individuals, with teams, and as organizations. Then, it presented concepts tied to individual factors for engagement with the attitude, investment, motivation, and scenario analysis method. Next, by drawing on business and management research, the Availability, Interest, and Knowledge methodology provided a simple way to identify the alignment of the vision, mission, and theory of change by understanding the why, what, and how of your actions. Following this, the authors integrated the concepts of strategic planning and logic models with the Universal Model of Strategic Planning. The authors discuss the double diamond model to represent the complex web of partnerships and the framework developed for communication and collaboration amongst stakeholders. The result is the Collaborative Convergence Pyramid framework for negotiating understanding within a new common space being generated together. Finally, the work concluded with a discussion of the vital roles collaborative infrastructure and strategic planning played in facilitating the Convergence Research approach with a multi-stakeholder coalition.

Keywords: *Inter-disciplinary, Trans-disciplinary Convergence, Collaboration, Partnerships, Strategic Planning, Collaborative Convergence Pyramid framework (CCPF).*

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1. Introduction

During the 20th century, science fiction often envisioned future developments where innovations lead to humans transcending their limitations. Distinct things like human thought and artificial intelligence are brought together. In the 1990's the concept of the technological singularity was proposed as a future in which humans and technology are brought together to be indistinguishable "The first to use the concept of a "singularity" in the technological context was John von Neumann" (Shanahan, 2015, p. 233).

This new hybrid of a converged human and computer is seeming to arrive through many paths but in the end, something new emerges that is not human nor machine. This new integrated whole creates something new where both humans and machines are no longer distinguishable from one another and the new construct has transcended the previous definitions which are now inadequate to describe it.

Similarly, in the 1960s Thomas Kuhn envisioned the way disciplines changed and revolutionized their understandings of their field. He described this as paradigm shifts that had a process of discovery, debate, acceptance, and eventual replacement of the old with the new. As knowledge grew the disciplines of science shifted to embody the new understandings that arose. At times, however, this revolution may not lead to a change but a split.

> "In the postscript to the second edition of *The Structure of Scientific Revolutions* Kuhn says of paradigms in this sense that they are "the most novel and least understood aspect of this book" (1962/1970a, 187). The claim that the consensus of a disciplinary matrix is primarily agreement on paradigms-as-exemplars is intended to explain the nature of normal science and the process of crisis, revolution, and renewal of normal science" (Bird, 2018).

The new discipline emerges out of the old as a sub-discipline or new working space as a way to integrate the understanding and work of two or more fields. In both cases, the idea of transformation for the shift and emergence for the new outgrowth does not capture the same transcendent picture as convergence.

This idea of merging two things to form a hybrid that eventually converges into an entirely new thing is at the heart of this discussion. The stages that move towards convergence and how that differs from other ways of innovation in research and disciplinary studies is an essential way of understanding many fields. The work describes herein deals with more than the labeling of collaborative efforts in a way to distinguish multi-disciplinary work from inter-disciplinary. It goes much further to illuminate the variety of types of convergence that are discussed and how each has similar but distinct aspects connected to the context and application of each. Moreover, it is necessary to clarify the key factors for operating at different levels to understand where you may currently be working and gain an understanding of the methods for moving towards a more convergence research approach.

In 2005 NAS brought forth the idea in “Inter- and Trans- Disciplinary research” (National Academies (U.S.) et al., 2005). In 2014 they presented the book “Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond” (National Academy of Sciences, 2014). In 2018 NSF presented the “Dear Colleague Letter: Growing Convergence Research” (National Science Foundation, 2018). Finally in 2020 NSF presented the webinar “NSF's Big Idea: Growing Convergence Research” (National Science Foundation, 2020).

Key to these efforts is the ability of individuals and organizations to collaborate and share knowledge and ideas. If all that is done is labeling, the work falls short of what will be the new heretofore-unseen perspective on a problem. As new space is created in which those practitioners create collaboratively, the new tools and methods for understanding and solving problems, Convergence Research is born. It

is this transcendence that may be sought to envision and attain the true change the future will bring. Nonetheless, the path has many steps and the conception of Convergence Research is a continuum from little convergence to full transcendent convergence in which a new paradigm is created in an emergent area of understanding.

The paper aims to clarify terminologies related to Convergence Research especially for complex problems and provide methodologies for assembling and working with collaborators, partners, and stakeholders. All of these require collaboration and often an understanding drawn from a variety of disciplines. This paper will provide a series of core principles that are needed to define and describe collaborative research at each of these interfaces. Then it moves on to discuss key factors for engaging in collaborative partnerships as individuals, with teams, and as organizations. Then concepts from organizational behavior and leadership research tied to individual factors for engagement will be examined through one's Attitude, Investment, Motivation, and Scenario (AIMS). Next, by drawing on business and management research, the Availability, Interest, and Knowledge (AIK) methodology will provide a simple way to identify the alignment of the vision, mission, and theory of change by understanding the why, what, and how of your actions. Following this, the article integrates the concepts of strategic planning and logic models with the Universal Strategic Planning (USP) model. The authors discuss the double diamond model to represent the complex web of partnerships and the framework developed for communication and collaboration amongst stakeholders. The result is a framework for negotiating understanding within a new common space being generated together. This article concludes with a discussion of the vital roles collaborative infrastructure and strategic planning played in facilitating the Convergence Research approach for the multi-stakeholder coalition.

2. Background: Terms needed to understand the Convergence Research approach

This article aligns its conception of the convergence research approach with the National Academy of Sciences (NAS) and the National Science Foundation (NSF). NAS states that convergence research will: “capture two dimensions: the convergence of the subsets of expertise necessary to address a set of research problems, and the formation of the web of partnerships involved in supporting such scientific investigations and enabling the resulting advances to be translated into new forms of innovation and new products" (National Academy of Sciences, 2014, p. 17). “Growing Convergence Research at the National Science Foundation was identified in 2016 as one of 10 Big Ideas for Future NSF Investments (National Science Foundation, 2019). Convergence research is a means of solving vexing research problems, in particular, complex problems focusing on societal needs. It entails integrating knowledge, methods, and expertise from different disciplines and forming novel frameworks to catalyze scientific discovery and innovation. Convergence research is related to other forms of research that span disciplines – trans-disciplinarity, inter-disciplinarity, and multi-disciplinarity. It is the closest to trans-disciplinary research which was historically viewed as the pinnacle of evolutionary integration across disciplines.

> “NSF identifies Convergence Research as having two primary characteristics:
>
> - Research-driven by a specific and compelling problem. Convergence Research is generally inspired by the need to address a specific challenge or opportunity, whether it arises from deep scientific questions or pressing societal needs.
> - Deep integration across disciplines. As experts from different disciplines pursue common research challenges, their knowledge, theories, methods, data, research communities, and languages become increasingly intermingled or integrated. New frameworks, paradigms

> or even disciplines can form sustained interactions across multiple communities" (NSF, 2016a, p. 1).

NSF describes convergence as a new paradigm that requires collaboration not just of individual representatives of different academic disciplines but from all sectors—academic, government, private, not-for-profit, etc. These collaborations can then utilize a clear collaborative infrastructure to effectively communicate and plan to overcome the challenges facing society. This new common framework might, "afford solving the problem that engendered the collaboration, developing novel ways of framing research questions, and opening new research vistas" (NSF, 2016a, p. 1).

The NAS also participated in the description of Convergence Research in a report that acknowledged that the terms and concepts related to Convergence Research are complex and can be confusing.

> "The key message of convergence, however, is that merging ideas, approaches, and technologies from widely diverse fields of knowledge at a high level of integration is one crucial strategy for solving complex problems and addressing complex intellectual questions underlying emerging disciplines. Of necessity, convergence requires an open and inclusive culture, and requires practitioners to move beyond a single language to being conversant across disciplines and to building a common set of concepts and metrics and a common understanding about goals" (National Academy of Sciences, 2014, p. 20).

Based on these two broad descriptions of the approach, it is clear that Convergence Research requires collaboration on various levels and between wide ranges of partners requiring effective communication to generate knowledge, plan and measure progress. At the same time, those individuals engaged in this activity must operate at many levels of engagement as individuals, disciplines, organizations, and

systems come together to understand, describe, and solve challenges often with newly created methods and tools. In order to gain a better grasp of how these various separate agents understood the concept of the Convergence Research approach to research and its necessary efforts and parts, a literature review was undertaken.

A scenario is the exact parameters that define the wide range of factors that affect an activity, including the goal sought, the actors involved, the situation, context and circumstances that limit those involved, and many other things that influence the ability to have agency, act, and solve problems. IN any scenario, these factors define what may be achieved and help outline the ways problems are approached and solved. One of the greatest limits is our thinking and assumptions connected to the collection of resources including human capital available to the team working on the problem. Before delving into the more complex concepts related to the Convergence Research approach, understanding some of the common disciplinary conceptions of the concept of convergence is required. As mentioned above, these disciplinary foundations are essential but not sufficient especially as new means of communicating are developed to allow more complete integration of work while allowing for the emergence of innovation to meet the challenges faced. The basic idea of convergence versus divergent thinking starts the discussion.

At the most general level, we can examine critical thinking and problem solving described with the terms convergent and divergent “Convergent and divergent thinking are two poles on a spectrum of cognitive approaches to problems and questions (Duck, 1981). On the divergent end, thinking seeks multiple perspectives and multiple possible answers to questions and problems. On the other end of the spectrum, convergent thinking assumes that a question has one right answer and that a problem has a single solution (Kneller, 1971). Divergent thinking generally resists the accepted ways of doing things and seeks alternatives. Convergent thinking, the bias of which is to assume that there is a correct way to do things, is inherently conservative; it begins by assuming that the way things have been done is the right

way. Divergent thinkers are better at finding additional ideas, whereas convergent thinkers have a more difficult time finding additional ideas. Convergent thinkers run out of ideas before divergent thinkers. However, convergent thinking strengthens the ability to bring closure and to conclude problems" (Kim & Pierce, 2013).

As our world grows in complexity and connection, problems also increase in similar ways. As we engage in research that examines systems like those that are needed for social innovation, the level of complexity grows as the scope and scale of the challenges increase exponentially. These systems require new methods to, "adequately evaluated and managed using single-domain approaches. Problem-solving must go beyond a single application field, discipline, or pathway. A general problem-solving strategy for all these cases is convergence" (Roco, 2020). Convergence Research can do more than show the intersection and means of integration of academic disciplines. The NAS put forth that Convergence Researh goes beyond inter-disciplinary approaches to allow for transcendence. NAS describes the disciplines coming together so their practices and methods form bodies of knowledge.

> "In this way, convergence represents an expanded form of interdisciplinarity in which bodies of specialized knowledge comprise "macro" domains of research activity that together create a unified whole. When integrated effectively, these convergent macro domains offer the possibility of a new paradigm capable of generating ideas, discoveries, methodological and conceptual approaches, and tools that stimulate advances in basic research and lead to new inventions, innovations, treatment protocols, and forms and strategies of education and training" (National Academy of Sciences, 2014, p. 21).

This is mirrored by researchers at MIT as they describe a view of Convergence Research applied to solving problems "The merging of distinct technologies, processing disciplines, or devices into a unified whole that creates a host of new pathways and opportunities" (Sharp et al., 2011). This type of work can only be

achieved by many individuals and groups coming together to collaborate with a common vision and open lines of communication. Others also discuss the need for inter-disciplinary and trans-disciplinary work. Rocco (2013) discusses how convergence is bringing disciplines of applied and pure research together with technology and new applications to seek innovations and new understandings. Although placing convergence in a very broad context, the report emphasizes a critical role of the merging of life and physical sciences expertise. In their chapter *Implications: Human Health and Physical Potential*, for example, Urban and Radzinski state, "over the next ten years, the major scientific infrastructure needed will be an effort to define these 'laws of biology' within a convergence approach that nurtures engagement of the physics and physical sciences research communities" (Urban et al., 2013, p. 184).

It is clear that research that seeks to move towards transcendence will work towards a trans-disciplinary collaboration. The degree of convergence for this type of research approach will rest upon several key factors described by the NSF collaborative infrastructure discussed below. First, it is necessary to explore the conception of collaboration found in the literature.

2.1. Degrees of Disciplinary Collaboration.

At the most general level, the idea of collaboration is a measure of the degree that individuals work together and share a vision for the goals and measures of success. In the academic arena, researchers often work alone or with student followers. At times, research teams collaborate to find synergy in their work and cooperate to enhance the results. However, for social innovation, the sense of collaboration envisions this as much more involved. Education is a good example of the need for social innovation to attain the ends sought for improvement. "Collaboration has become a fundamental school improvement strategy that denotes two or more people, groups, or organizations working together to reach goals that could not be accomplished by individual entities working independently" (Frey, 2018, p. 320).

The Convergence Research approach goes far beyond the individual researcher or a uni-disciplinary team of researchers cooperating. As described above, when complex social problems are faced which require innovations, the Convergence Research approach requires collaboration that is more diverse by larger teams from outside academia. To discuss that more complex space and the degrees of the scope of disciplines, the researchers once again delved into the literature to identify the key factors that distinguish and separate the different types of disciplinary studies from non-collaborative through to the fully transcendent collaborative teams needed for Convergence Research approaches to be effective.

> **"Disciplinarity** refers to a particular branch of learning or body of knowledge whose defining elements—such as objects and subjects of study, phenomena, assumptions, epistemology, concepts, theories, and methods—distinguish it from other knowledge formations." (National Academy of Sciences, 2014, p. 44). This describes the common understanding of a domain or subject. For the more complex scenarios being approached with convergence, higher degrees of collaboration needs to be described. However, just adding more individuals is not the answer. Each of those individuals must bring with them different perspectives, human capital, and other resources. Otherwise, the team of researchers represents a Uni-disciplinary approach. NAS describes this as "researchers from a single discipline, field, or area of established research and education practice work singly or collaboratively to study an object or to address a common question, problem, topic, or theme" (National Academy of Sciences, 2014, p. 44).

Thus, to utilize convergence means more than working with multiple people. Based on what is presented next, the Convergence Research approach is more than just working with individuals or organizations from different domains or sectors by receiving funding or other resources. The degree of connection beyond one's

academic training and organizational affiliation determines a picture of the type and magnitude of collaboration. These types of collaborative engagement are one key factor to recognizing the research approach as moving towards convergence. The steps or degrees of engagement identified are termed: Multi-, Co[4]-, Inter-, and Trans-disciplinary for this discussion. Depending on the scenario and especially the language and culture of the participants, these terms may be used differently or other terms substituted for these prefixes. The aim here is to describe the nature of the connection and shared work being undertaken and goals attained by the entities involved. When considering the core measure of collaboration, these different levels can be seen by the researcher in academia naming the relationship they have with others as the relationship moves from multi-disciplinary to trans-disciplinary: delegation, cooperation, connection, integration, and innovation (see Figure 1).

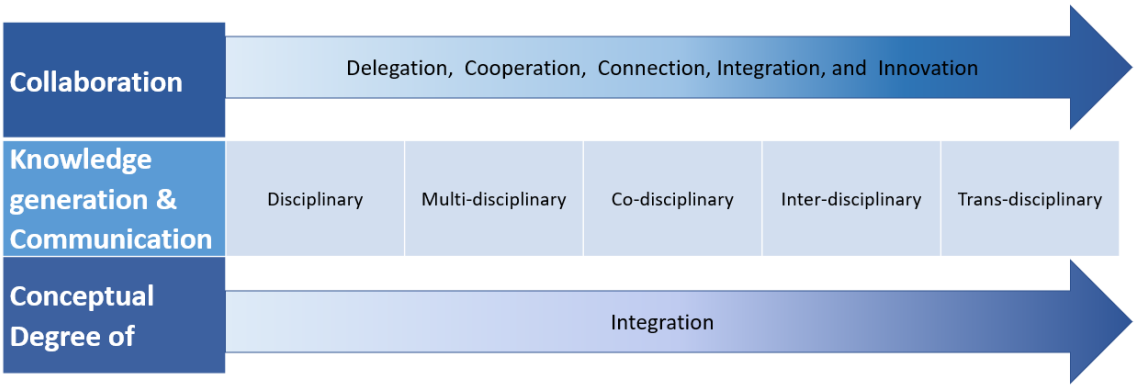

Figure 1.- Collaborating Toward Convergence.

The first degree of collaboration is termed multi-disciplinary and gathers individuals and organizations together under a common goal to work independently. Often there is a leader or lead organization that delegates work, drives actions, and produces final reports.

> "**Multi-disciplinary** juxtaposes two or more disciplines focused on a question, problem, topic, or theme. Juxtaposition fosters wider information, knowledge, and methods, but disciplines remain separate

[4] When we refer to co-disciplinary it encompases all related terms such as: Cross- or Across-.

> and the existing structure of knowledge is not questioned" (National Academy of Sciences, 2014, p. 44).

Though people may work together, everything is kept separate and each separate actor produces products or findings that are gathered together and not integrated. Most importantly, this type of arrangement does not seek to adjust the separated methods of investigation and only has them applied and gathered together outside of the scenario being investigated.

> "**Multidisciplinary approaches** juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voices, in encyclopedic alignment, an ad hoc mix, or a mélange. Disciplinary elements retain their original identity. In short, the multidisciplinary research product is no more and no less than the simple sum of its parts" (Wagner et al., 2011).

Many times, disciplinary actors find common overlap in goals, methods, or other aspects of their scenario. This often happens as government agencies or private companies work with universities on public-private partnerships or funded research leading to cross-disciplinary work that works across two or more disciplines of study.

In this work we identify a situation that exists between multi- and inter-disciplinary as mentioned above we termed this **Co-disciplinary** and defined as: the cooperation between two or more disciplines with the added value that they are sharing and trying to improve communication and collaboration through cooperation. This conception of sharing leads to two perspectives of how it is accomplished – Cross and Across – Across is envision as passing knowledge across a bridge, as an exchange or other form of connection. On the other hand, Cross- brings the disciplines into a commons space in which there is an intersection. The

terms used to described this vary depending on how the work is characterized, motivated, or undertaken.

A common example that might look at multi- and co-disciplinary work on a continuum could be when an external evaluator is used during the investigation of an educational application of a technology product. If the evaluator is just a consultant that has work contracted out and delegated so final findings are presented, it would be a more multi-disciplinary collaboration. If, however, the findings are used to adjust work and the understandings generated by each discipline are used to have collaborative meetings to better understand the endeavor, this would be more co-disciplinary. The two parallel disciplines communicate as they work separately so that the convergence is more about the way collaboration and communication interface rather than the knowledge truly being integrated.

This leads to a much more integrated approach to collaboration in which the work is undertaken together and communication and knowledge creation are planned with shared aspects throughout the process. This next degree of collaboration is inter-disciplinary.

> "**Interdisciplinary** from two or more disciplines focused on a complex question, problem, topic, or theme. The scope and goals of research programs range from incorporating borrowed tools and methods and integrating them into the practice of another discipline to generating a new conceptual framework or theoretical explanation and large-scale initiatives. The key defining concept of interdisciplinarity is integration, a blending of diverse inputs that differs from and is more than the simple sum of the parts. Individuals may work alone, but increasingly research is team-based. Collaboration introduces social integration into the process, requiring attention to project management and dynamics of communication" (National Academy of Sciences, 2014, p. 45).

This definition stresses integration and complex problems.

> "The critical indicators of interdisciplinarity in research include evidence that the integrative synthesis is different from and greater than, the sum of its parts:
> • Micro-combinations of models or global schemes that unify disparate approaches
> • Consulting and partnering modes, not multidisciplinary contracting of services
> • Coordinated and collaborative inputs and organizational framework
> • Formation of a new community of knowers with a hybrid interlanguage
> • Generation of new insights and disciplinary relationships
> • A larger, more holistic understanding of the core problem or question
> • Altered perspectives and revised hypotheses" (Wagner et al., 2011).

These factors describe the revolution of paradigms to incorporate new or different perspectives. However, this integration does not necessarily create a new space or new methods for the larger disciplines involved. This emergence is a revolution in a domain or evolution of a new discipline often without a larger dimension of innovation. Tools and methods needed for social innovation challenges require an even higher degree of collaboration to face these more complex and persistent problems.

This brings us to the concept of transcendence as a way to go beyond just the intersection of two or more disciplines or the parallel work of co-disciplinary investigations. **Trans-disciplinary** approaches bring the community of the academy together with members of the other sectors of society including those facing the problem and working to solve it. "The construct goes beyond interdisciplinary combinations of existing approaches to foster new worldviews or domains" (National Academy of Sciences, 2014, p. 45). Thus, where inter-

disciplinary work brings things together and finds a way to accommodate the methods that exist in other domains for use in the discipline, trans-disciplinary research creates new methods and procedures. Inter-disciplinary research is "based upon a conceptual model that links or integrates theoretical frameworks from those disciplines, uses study design and methodology that is not limited to any one field, and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process" (Aboelela et al., 2007, p. 331). On the other hand, the trans-disciplinary approach works to synthesize knowledge and practice from different domains to create a new set of theories and frameworks. The results from this approach create products that are greater than the sum of the parts brought together to generate them.

> "The term has also connoted a new mode of knowledge production that draws on expertise from a wider range of organizations, and collaborative partnerships for sustainability that integrate research from different disciplines with the knowledge of stakeholders in society. Here too, the transdisciplinary product is greater than the sum of its parts, though the scope of the overall effort is more comprehensive and the parts may be more diverse (Wagner et al., 2011, p. 16).

Although transcendence moves our discussion very far along towards convergence the two concepts are not synonymous. Transcendent Research can occur at varying levels of complexity and with a range of partners. It results in moving the integration of disciplines towards innovations in the domain of knowledge communication and at times creates new disciplines (see Figure 2). Convergence Research on the other hand addresses larger and more complex problems that require sustained continuous innovation that generates new domains and degrees of freedom as it integrates and innovates. In order to attain this, the ongoing collaboration of large numbers of individuals is needed. However, that personal connection requires work and tools to facilitate the development of effective teams.

The next section discusses one simple method for considering factors that may impact collaboration termed AIMS.

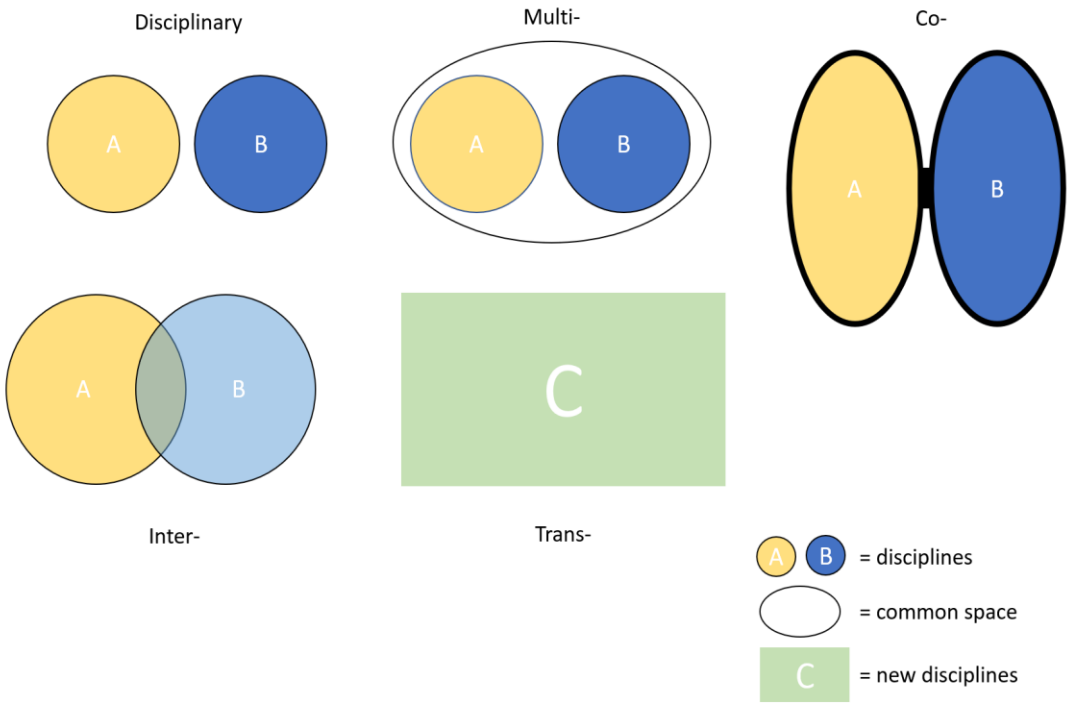

Figure 2.- Continuum of the Interaction of disciplines.

3. AIMS to Enhance Synergy

Our model for understanding how to align person-to-person connections is AIMS (Attitude, Investment, Motivation, Scenario). The AIMS model provides areas to consider related to the interpersonal levels especially as individuals are assigned to projects. At times, the leaders of a team, organization, or movement are also the ones engaged in the work. However, more often, the actual actors and agents of change are operating for different reasons and at a different level of engagement than the commitment of a leader or outlined in a contract. As we examine the core ideas of collaboration and communication, the need for researchers to understand and appreciate a variety of factors tied to those they support, will work with, direct, and engage in collaborative research with is essential. AIMS outlines several of the

most impactful factors for individuals within the scenario: attitude, investment, motivation, and situation.

First is *Attitude* that describes the perspective of the person and how he or she interacts with others. No matter how well aligned an individual or organization may be, the attitude of the members of a group or team has towards one another directly impacts the way collaboration and communication happen. Attitudinal factors and preconceptions individuals maintain have an impact on the effectiveness of teamwork. Though first impressions often persist, the attitude of individuals can change and be adjusted depending on the group dynamic and influence of leadership and the larger goals of the collaboration.

The second aspect is *Investment*, in all senses of the term. For many just having time to work with others and access is key. The investment of the individual is a baseline level at the outset but can change as time goes on. All the aspects of how much time, effort, human capital, or other external resources are given to the work of the project make a difference in the way collaboration moves forward. Often the level of investment, both tangible and intangible, relate to other relationships and facts connected to the level of engagement of the participants. How much any one person is willing to give of themselves and their resources depends on many factors but can greatly impact their role in the collaboration and thus the success of the project.

Next is the concept of *Motivation* that plays a major role in *Effectiveness*. As with any goal-driven task, the motivation of the participants is an essential part of success. Moreover, motivations that are more self-serving and individualistic can negatively affect a project that requires collaboration. Seeking reputation or personal enrichment can often break down a team and break down lines of communication or interfere with effective collaboration. Motivation can often be adjusted with team-building and effective leadership strategies. However, internal motivation generated by buy-in to the vision of the program and a clear sense of

progress is often more effective than external motivation. Generation of motivation to the project through rewards does not tend to lead to sustainable change. Internal motivation is more persistent and leads to more positive attitudes, greater investment, and greater participation in the efforts to find common ground and more open lines of communication (McClelland, 1988; Ryan & Deci, 2000).

Finally, each member of the collaboration needs to understand and appreciate the *Scenario* in which the works is being accomplished. Within every scenario is the the location and context of the work to be undertaken. Understanding the situation of those involved to understand the context of the interactions, the circumstances that have led them to be part of the collaboration, and of course, the exact factors impacting the moment all play a role in the way any communication unfolds and any collaboration works.

An example of AIMS being applied can be the way you distinguish between a student choosing to volunteer (volunteers), do community service (service), or participate in a civic engagement project (engagement). Though all three may be seen as similar, the level of AIMS can impact the approach to the interactions and the way they are spoken about by the person participating,

Volunteers exchange their time and effort for good feelings, experience, networking, and in some cases, credit in courses or for organizations like honors college or clubs/ fraternity/sorority. Typically, the goals and actions are set down by others and not tied to the volunteer except in the choice of group to work with or help. In these cases, personal attributes and motivation are external to the person and the investment is often time and effort in direct exchange for some specific return dictated by the scenario.

Service goes beyond volunteering by leveraging the abilities and capacity to aid in the work being done. Service is typically done over time and involves the volunteer working with the organization to attain the goals and mission in line with the vision.

The intent of the work matches the one being serviced and so makes an ongoing contribution. A person providing service will invest more human and social capital to enhance the outcomes in the given scenario. Often, the motivation moves from external to internal in cases of service compared to volunteering.

Engagement goes beyond service so that the volunteer becomes a leader and works with the community and collection of stakeholders to aid those being served or the actions being taken. The overarching vision brings the entire community into play as the work has the volunteer become part of and engaged with the interaction and their initiatives. This shift in the role and often motivation of the volunteer is accompanied by a change in attitude and level of investment. When fully engaged, the volunteer will work to achieve the mission and participate in decisions to change the scenario. For those seeking collaborators, it is important to consider what level of AIMS applies to those they are engaging and how the interpersonal connections align as the scope and scale of the project grows to the level of social innovation.

4. Convergence Research Approach and Collaborative Infrastructure

What has been examined thus far, deals with degrees of collaboration as described in the literature. NSF has put forth a framework for any group of individuals organizations, or networks to come together to work on complex problems. The collaborative infrastructure describes common elements needed to facilitate the Convergence Research approach, especially when applied to social innovation initiatives. The NSF INCLUDES project is one of NSF's 10 Big Ideas and promotes Convergence Research requiring collaborative infrastructure. "The Big Ideas represent unique opportunities to position our Nation at the cutting edge of global science and engineering leadership by bringing together diverse disciplinary perspectives to support Convergence Research". This Convergence Research approach is used for the NSF INCLUDES solicitation "A hallmark of NSF INCLUDES is the focus on the five design elements of collaborative infrastructure

to achieve systemic change" (NSF INCLUDES, 2021, p. 2). To accomplish the Big Ideas, NSF INCLUDES requires the use of the collaborative infrastructure.

> "Collaborative infrastructure refers to the process by which partnering organizations come together to map out mutually reinforcing activities through (1) shared vision, (2) partnerships, (3) goals and metrics, (4) leadership and communication, and (5) expansion, sustainability, and scale" (NSF INCLUDES, 2021, p. 7).

This infrastructure rests on a shared vision of the charge for the approach that includes common actions and shared agency. This involves the second element of partnerships, which are essential for organizations to share resources and magnify effort through the synergy of activity. These partnerships and shared vision are developed, maintained, and grown through the third element, leadership, and communication. Without guidance and open lines with a common understanding, the Convergence Research approach will not work. All parties need to share and collaborate as the work transforms current understanding through negotiation and new developments of the scenario. The fourth element shared goals, and metrics are key to the operational work of the Convergence Research approach. By collaboratively identifying goals and the measures for how they will be attained and thus success determined, the Convergence Reearch approach can transcend simple investigations or even integrated approaches. These four elements work together to co-create the tools and activities necessary to plan for and act upon the problem. It also allows others to understand, participate in, and support the Convergence Research. The last element of the collaborative infrastructure asks the network of individuals and organizations to go beyond simple plans or events. To be successful, at the needed scope of the social innovation required to tackle the complex problems, the collaboration must expand, be sustainable, and scale to the level required for the approach to have an impact with its outcomes. Bringing these elements together demonstrates that Convergence Research as an approach will need more than just collaboration but without it, the approach will not be effective at the needed scale of change.

This leads the discussion to what NSF and NAS truly consider the Convergence Research approach:

> "Convergence is an approach to problem-solving that cuts across disciplinary boundaries. It integrates knowledge, tools, and ways of thinking from life and health sciences, physical, mathematical, and computational sciences, engineering disciplines, and beyond to form a comprehensive synthetic framework for tackling scientific and societal challenges that exist at the interfaces of multiple fields. By merging these diverse areas of expertise in a network of partnerships, convergence stimulates innovation from basic science discovery to translational application. It provides fertile ground for new collaborations that engage stakeholders and partners not only from academia, but also from national laboratories, industry, clinical settings, and funding bodies" (National Academy of Sciences, 2014, p. 1).

This demonstrates the need for Convergence Research and its reliance on collaboration facilitated by collaborative infrastructure. However, the essential steps to find collaborators, plan a successful Convergence Research project, and develop the other aspects of convergence efforts like communication, knowledge creation, strategic planning, amongst others are not addressed. The remainder of the article will discuss the methods used to find possible collaborators and co-design the initiative with the Convergence Research approach in mind. Though these tools can be used for other applications, they are what was utilized for the author's research project with NSF to develop the coherent resilient converged research plan that was implemented and adjusted with the range of partners.

The problem many people have with starting the Convergence Research approach is that it requires collaboration, communication, and leadership. To plan for sustainable innovation, you need project management and strategic planning.

5. Strategic Planning Guide (SPG)

The implementation of the strategic process in sponsored research plans adds direct value to the research team by providing them with tools that will allow them to migrate from emergent planning to formal planning. In addition it fosters core competencies to generate new models of value transmission that will allow them to adapt, be resilient and adjust to the situation in order to make contributions to the solutions of complex problems. The core steps in the strategic planning guide (SPG) are structured around the ideas found in the business and administration literature (Acle Tomasini, 1990; Lema, 2004; Mintzberg, 1994; Porter, 1995).

To approach the preplanning process before the strategic planning stage, we follow several models and methodologies to assess the current position of the research team and plan.

Preplanning Process before Strategic Planning:

- Dimensions of the construction of the strategic plan: preliminary analysis of resources
- Research analysis of the current economic context: industry, company, consumer behavior
- Design of future scenarios: country, industry, university, or company
- Definition of the strategic guide: Methodology, frameworks, and intellectual merit requirements
- Consulting design: Communication mechanism, execution of the “strategic guide”
- Constitution of mechanisms: Monitoring, control, execution.

Once this preliminary analysis is completed you will have identified a framework of the methodologies and intellectual merit required for your particular scenario. The next step will be the strategic planning stage where we will define and delimit the:

- Vision, Mission, and Just cause
- SWOT analysis (external and internal)

- Formulation of Goals and Metrics
- Strategy Formulation
- Program Formulation
- Principles and Values
- Implementation Expectations
- Control Expectations

Once the strategic planning is completed, the general strategies for approaching the scenario will be identified. This will help the process of establishing the collaborative infrastructure. Some of the specific methodologies used in the authors NSF INCLUDES project were: Design a logic model, develop a plan using the USP model, identify partners using AIK (see Figure 3).

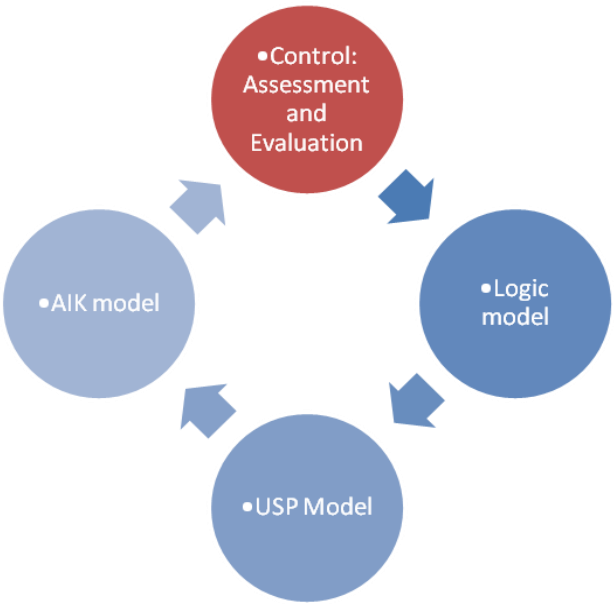

Figure 3.- Referential models for collaboration.

The remainder of this paper will elaborate on some of the models utilized by the authors as they engaged in their Convergence Research approach utilizing the Collaborative Infrastructure.

6. Logic model

In essence, the logic models are based on two general dimensions: The planned work and the expected results. Following closely the dimensions of the theory of change: assumptions and external factors. Logic models can be used as planning and/or evaluation tools. The authors agree with the ideas of Shannon and Weaver (Shannon & Weaver, 1963) and adopt the Kellogg Foundation's definition of logic models "The term logic model is frequently used interchangeably with the term program theory in the evaluation field. Logic models can alternatively be referred to as theory because they describe how a program works and to what end" (2004, p. 2). The ideas presented in this section are based on the intersection of logic models with the theory of change (Armitage et al., 2019; PCAR, 2018).

6.1. Evaluation and work plans:

The logic model allows you to recruit partners and complete the goals and metrics necessary to innovate and make your program sustainable.

7. Universal Strategic Planning Model: USP Model

In academic research, it is often necessary to collaborate with different organizations and associations, both public and private. There are several models and methodologies (Basarab Nicolescu, 1996; Ravitch & Mittenfelner Carl, 2020; Scholz, 2020; Yáñez León, Gerónimo Ramos, et al., 2021) for the development of disciplinary and multi-disciplinary research that will generate collaborative research (Link, 2020). However, when the researcher chooses to participate in federal large Convergence Research initiatives as:

- "NSF INCLUDES" (2021).
- "NSF's 10 Big Ideas" (National Science Foundation, 2016).
- "The Brain Research through Advancing Innovative Neurotechnologies (BRAIN)" (NIH, 2021).

- “The Tissue Chip Project” (NIH & NCATS, 2015).
- NSF Integrated Support Promoting Interdisciplinary Research and Education (NSF, 2016b).

The research team will need to use an inter-disciplinary, trans-disciplinary, and/or Convergence Research approach to the problem. These programs require more involved planning with a greater emphasis on strategic planning.

The Universal Strategic Planning model (USP model) was designed to assist researchers with this need (see Figure 4). The model will create a graphic organizer similar to the logic model diagram with two added dimensions Pre-planning and Assessment (Yáñez León, Lipuma, et al., 2021, p. 1013).

8. The Availability-Interest-Knowledge (AIK) model

The Availability-Interest-Knowledge (AIK) model, is a Venn Diagram that represents the intersection of three dimensions of necessary resources for a common language to build communication and relations (see Figure 5).

The Venn Diagram will guide the three intersections between two dimensions (for example A+I). To have a common starting point it is necessary that the two parties involved have Availability of time and resources (A), Interest in what each other is doing (I), and finally Knowledge or expertise in a common domain (K). If only one or two dimensions are aligned, then it is not possible to initiate the collaboration.

8.1. The Scenarios

Each partner has a letter A or I or K but they are not the same, therefore, the collaboration does not start. Not aligned.

The first place where we have some alignment is when they have one element A or I or K in common, consideration of collaboration may appear but time and effort is necessary to increase the amount of alignment. We will represent with capital letters

having Availability, or Interest or Knowledge (AIK) and with lower case not having them (aik).

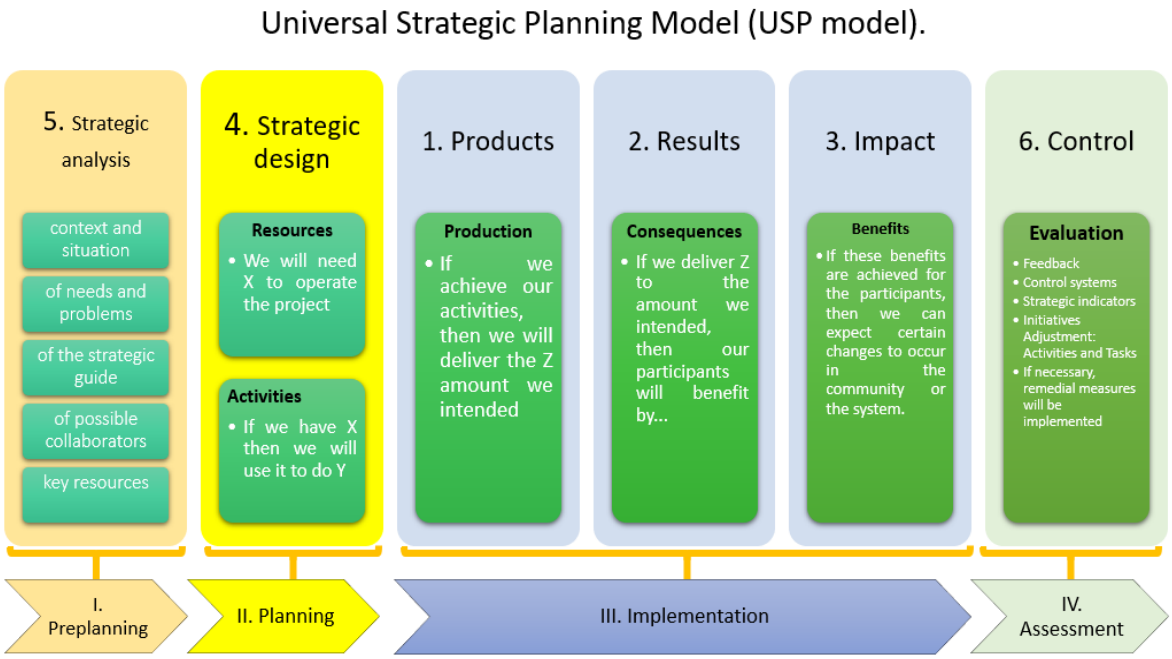

Figure 4.-Source "Modelo UPE: Una Herramienta Universal de Planificación Estratégica para la Investigación Académica" (Yáñez León, Lipuma, et al., 2021, p. 1013).

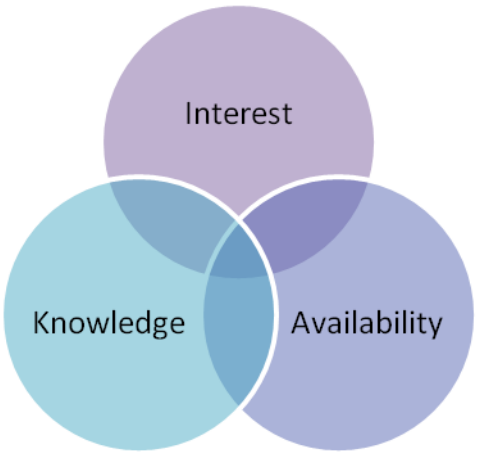

Figure 5.- The Availability-Interest-Knowledge (AIK) Model.

This model is seeking answers to three basic needs (see Figure 6):

Figure 6.- The AIK basic needs questions.

The Aik scenario.- An example of having only one element aligned is when an organization "X" has time and resources (A) but if they have no interest (i) or have a lack of knowledge (k) on what organization "Y" is doing this will lead to a non-collaborative state of the relationship between the two organizations.

The next scenario is when they have two elements in common. Collaboration might begin, but it may lead to false start if you cannot increase the level of aligned with the one missing element.
The AIk scenario.- If organization "X" has time and resources (A) and also, they have some interest (I) but have a lack of knowledge (k) on what organization "Y" is doing this will lead to a low collaboration state on the relationship between the two organizations due to the lack of understanding.

The last alignment is when all of the elements are present. This does not ensure effective collaboration but it reduces the obstacles as the organization try to move forward as they try to accomplish a sustainable partnership.
The AIK scenario.- If organization "X" has time and resources (A) and they have interest (I) and they have knowledge (K) on what organization "Y" is doing this will lead to a high collaboration state on the relationship between the two organizations.

9. The Generalized Double Diamond Model

The classic work of Porter "Competitive Advantage of Nations" introduces the diamond model to answer three essential questions around "consistent innovation" (Porter, 1990, p. 8).

> "The diamond has four interrelated components; (1) factor conditions, (2) demand conditions, (3) related and supporting industries, and (4) firm strategy, structure, and rivalry, and two exogenous parameters (1) government and (2) chance" (Cho & Moon, 2013, p. 126).

Porter's original diamond model explores one nation or one organization and has been extended to the generalized double diamond model (Cho & Moon, 2013, p. 123) whereby multinational or multi-organizational activity is formally incorporated into the model. The authors adjusted this model following the ideas of the "multiple linked diamond model" (Cartwright, 1993) changing the four interrelated components for; (1) Academy (Universities), (2) Government (International, Federal, State, and Local), (3) Organizations (Corporations, Private and non-profit organizations), and (4) Society (Communities and additional stakeholders), and two exogenous parameters (A) Challenges, and (B) Uncertainty. Challenges are unidirectional representing the pressure put on each of the entities in the collaboration. Uncertainty is bidirectional as it has an impact on the four components but it is also affected by them (see Figure 7).

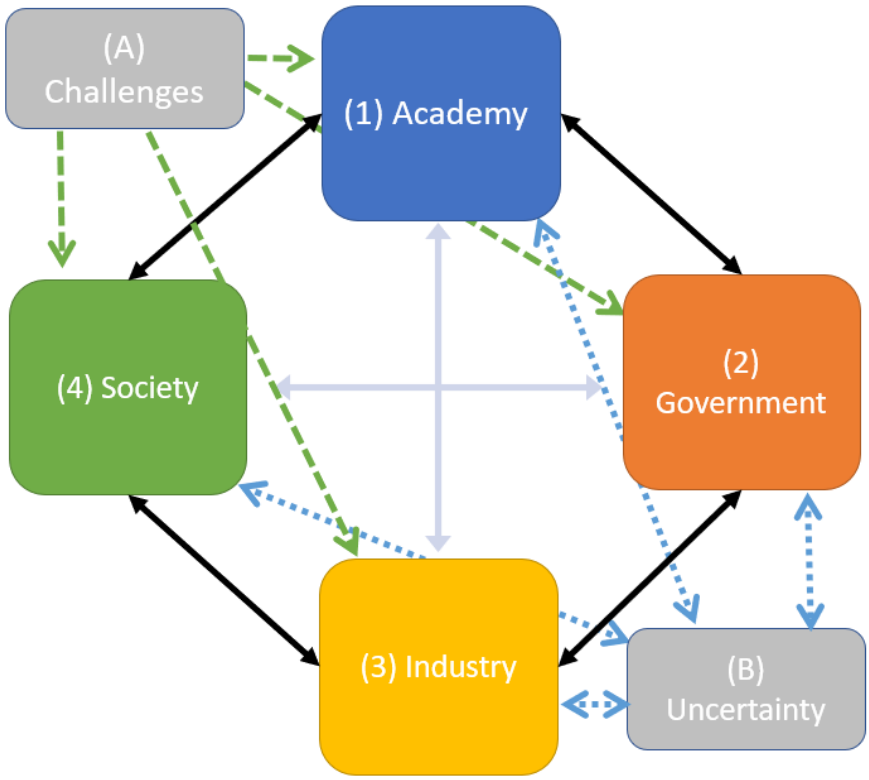

Figure 7.- Convergence Collaboration Diamond. Adapted from (Porter, 1990, p. 08).

The final adjusted Convergence Collaboration Dimond has then four courners of possible partnerships were we can weight the percentil of alignment and or relationships that an organization can have with this sectors (e.g.- if an organzaition has 100% of collaboration with all four sectors see Figure 9)

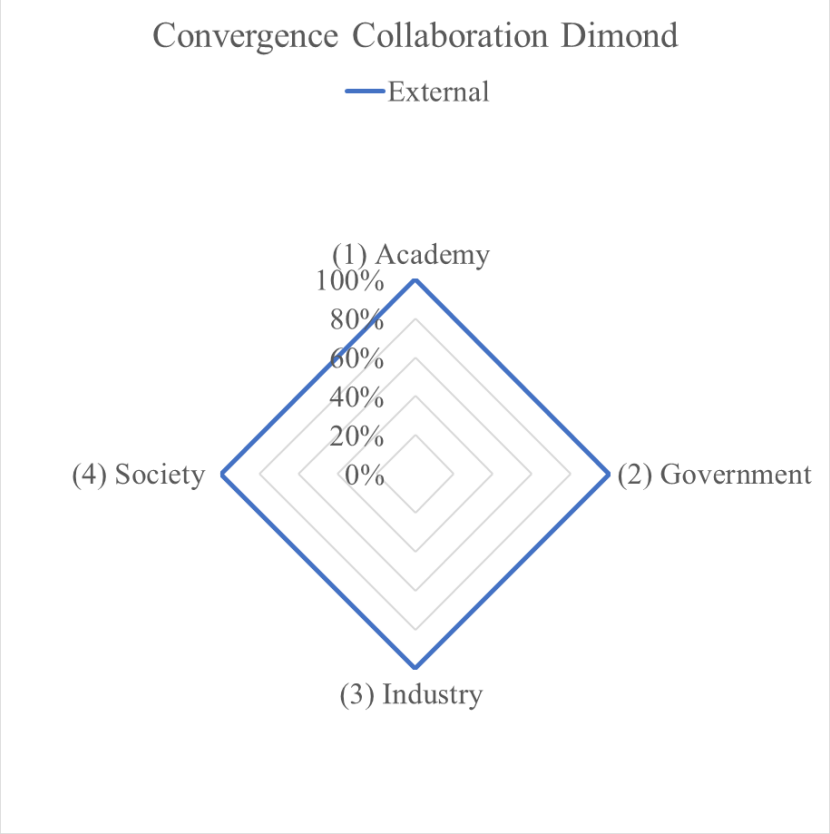

Figure 8.- Convergence collaboration Diamond an ideal example.

9. The Generalized Double Diamond Model in Convergence Research

Expanding the diamond model to the generalized double diamond model creates a web diagram (see Figure 9) that captures the external stakeholders and internal stakeholders' relationships of individuals and their organizations and or organizations and systems with this same sectors. Adding a second dimond or a second (different) organization will allow us to see the relationship on the web for the multi-stakeholder alignment by comparing the external stakeholder relationship with the sectors vs the internal stakeholder relationship (see Figure 9).

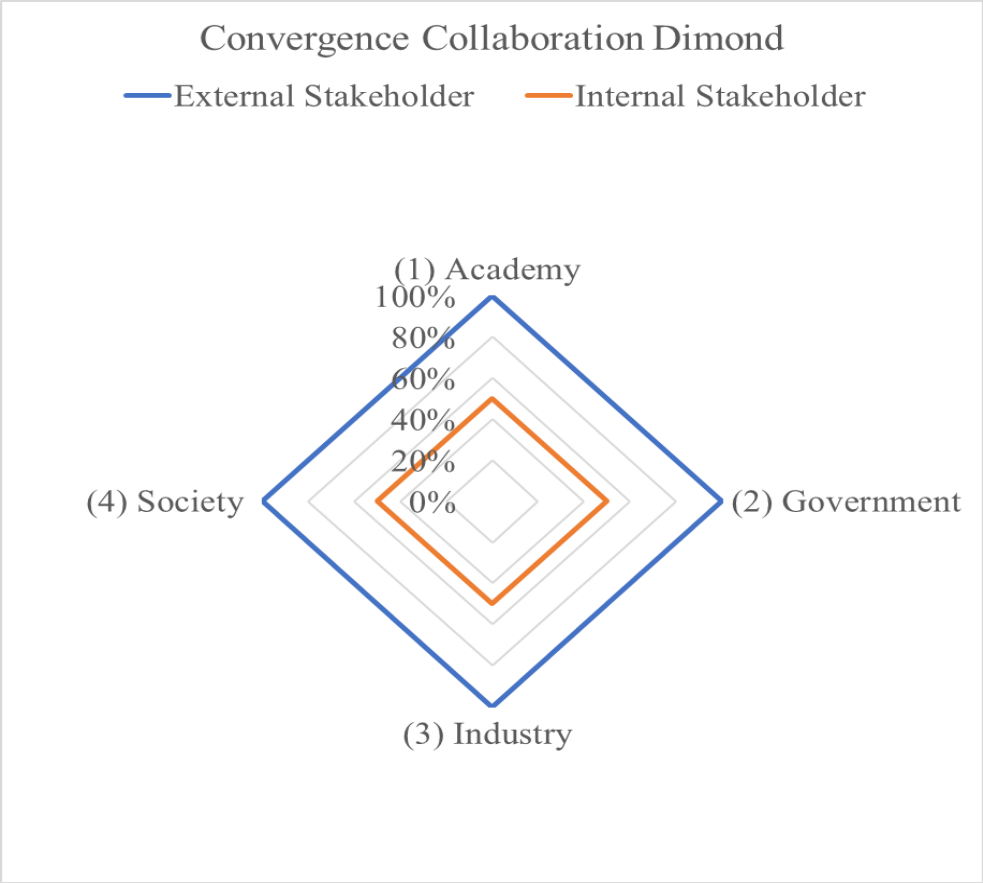

Figure 9.- The Generalized Double Diamond Model and ideal example.

9.1. Idealized Example

In this representation the External stakeholder has 100% of relationship with the four sectos and the Internal stakeholder has a 50%. Therefore, there is greater benefit for the Internal stakeholder as stablishing a relationship with the External stakeholder will add value to its organization.

9.2. Normal Example

A more real-world example, is when the External stakeholder has a strong relationship with the Academy (100%), good relationships with Industry and Government (80%) but a low relationship with Society (45%). The Internal stakeholder has low relationships with Academia and Industry (15%), good relationship with the Government (65%), and a strong relationship with Society (100%). Therefore, there is a common benefit for both stakeholders as the External

can benefit from the Intenal relationships with Society and the Internal will benefit from the External relationhsips with Academy and Industry (see Figure 10).
It is important to note that the two exogenous parameters (A) Challenges and (B) Uncertainty, still have an impact on both stakeholders.

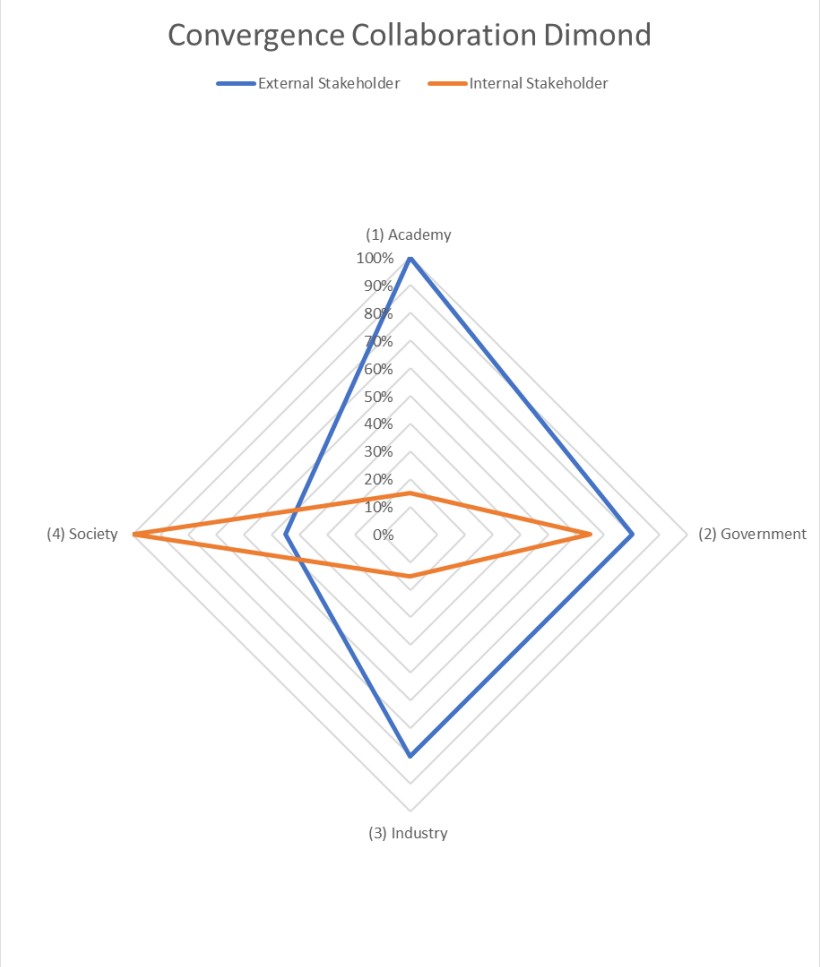

Figure 10.- The Generalized Double Diamond Model a normal example.

10. The Collaborative Convergence Pyramid

By combining the double diamond model with the collaborative infrastructure framework when utilizing a Convergence Research approach, you will add an additional degree of freedom as new domains and languages are created. The authors develop the Collaborative Convergence Pyramid as a framework to facilitate Sustainable Solutions and improve the trans-disciplinary communication between stakeholders both internally and externally and also amongst the four sectors

This current description is a representation of trans-disciplinary work because its focus is innovation, when applied to social innovation the goal is to work collaboratively to create a new space by creating a common focus (see Figure 11).

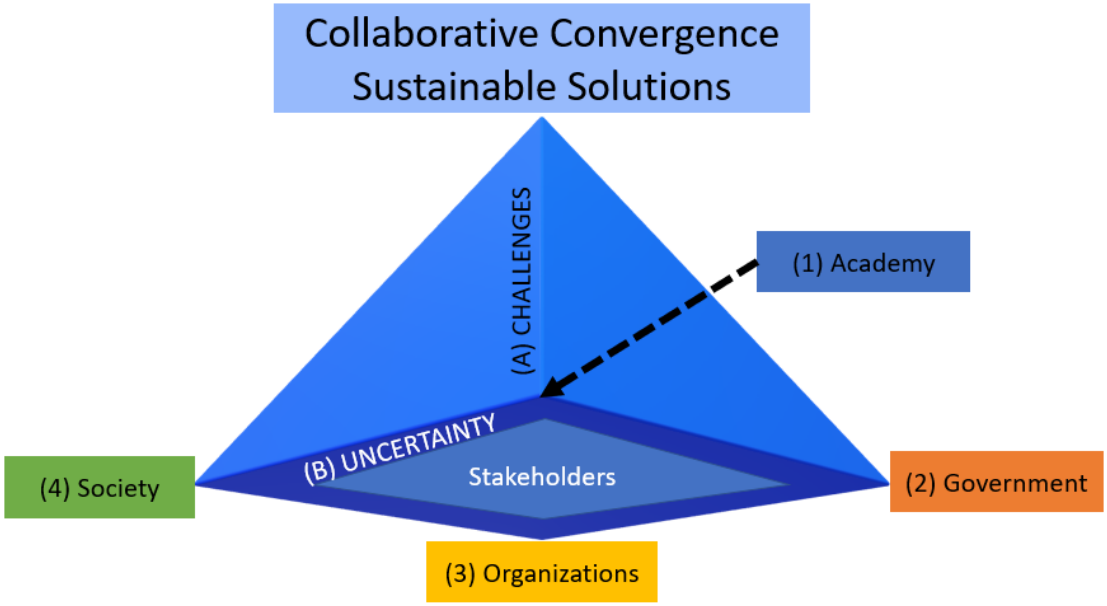

Figure 11.- Collaborative Convergence Pyramid.

Not every collaboration nor research seeks to be convergent or even transcendent. However, as the scope and scale of the project grows to meet the needs for social innovations, the new domains created are a necessary step forward. When the collaborative convergence research approach is applied to highly complex social issues, the resulting knowledge, language of discourse, and engagement are more resilient. The new domains created provide new norms of typical interactions.

10. An Application of Collaborative Convergence Research: STEM for Success

The understanding of the materials presented in this paper was developed during the authors' NSF INCLUDES research project. During this project, collaborators from K-12 schools, the US ARMY, Apple corporation, the New Jersey School Boards Association, and several other government, corporate, and not-for-profit groups along with community stakeholders came together to co-design, test, and refine the elements of the collaborative infrastructure. The LiFE Project, an NSF INCLUDES Design and Development Launch Pilot, which became the STEM for

Success program sought to broaden participation of females in STEM by promoting STEM experiences that would allow each participant to Discover, Engage, Access, Learn and Share (DEALS). This exploratory study sought to determine if STEM experiences lead to positive engagement by females in grades 3 to 6.

> "The elementary-middle school period is critical because, by 8th grade, many girls have left the STEM pathway forever. The key to reversing the trend is finding effective ways to display STEM as a collaborative, people-rich space in which girls can participate together, be themselves, and engage in exploration. Research indicates that girls prefer collaborative activities that can make a difference in the world. Partnering with a coalition of economically and racially diverse New Jersey elementary schools, Life will employ "is TEAM" learning strategies that encourage girls to apply the tools of various disciplines to investigate and solve real-world problems in an open environment of innovation, collaboration, and communication" (Bukiet et al., 2021)

Rather than apply a treatment or study the impact of a program, the project worked to build a collaborative team of invested stakeholders that had their own motivation. This allowed the project to be resilient in its design as changes occurred in the student participants, educators, administrators, project partners, and individual members from all the stakeholder groups. Rather than focusing on defining the initiative, the effort was focused on the co-design of the elements through collaboration with the actors who had agency at the point of contact in the given scenario.

> "It is important to be intentional and persistent in fostering a sense of partnership with all stakeholders…. While teachers applauded many aspects of the project's PD, they most appreciated the opportunity to bond with other teachers. Generally, teachers have few opportunities to interact and discuss ideas and plans with teachers at other schools and even within their own schools. Thus, the more time that PD provides for educators to discuss activities, desired supplies and to collaborate with one another, the better" (Bukiet et al., 2017).

This new domain of knowledge, agency, and language of the community was vital to the ability of the program to respond to major challenges. As with all education and the broader society, the COVID-19 pandemic has caused a major disruption in all activities. However, these challenges and related uncertainty did not undo all the work of the project. The work was able to go back to the planning phase and logic model to identify where the new needs would require changes in the current

conception of how the work was to be undertaken and proposed activities. As a result, the program was transformed into STEM for Succes and supported the community with what they required.

When the scenario significantly changed, the motivation of individuals was challenged, as new investments were required by the need to focus on the transition to new modes of instructional delivery. Moreover, STEM suffered as hands-on activities were denied access, and often only Math and English subjects were given priority. Nonetheless, our new domain enabled the stakeholders to engage with one another to provide insights and identify ways support could be provided to the community. STEM for Success worked to attain the same connection by creating virtual hands-on STEM experiences while distributing STEM starter kits to 500 groups to promote STEM experiences.

10.1. Developing a Collaborative Convergence Framework

Dought the varios models presented do not have to be followed in a prescribe order our research implemented the collection as shown below:

Preplanning

- Identify potential partners
- Proposing the work
- AIMS to find the individual stakeholders and collaborators at all levels that will collaborate with the program.
- AIK to align internal and external stakeholders

Grant award and the start of the program

- Construct and maintain the Collaborative Infrastructure
- SPG to test elements to increase effectiveness and respond to the scenario
- Develop a communication playbook
- Develop the Logic Model
- Operationalize the program evaluation
- Apply the USP model to develop and implement the SPG

The program expand to a Co-design approach

- AIK to recommit the internal and external stakeholders to the new approach
- The generalized double diamond

A new scenario developed due to COVID-19

- Return to the USP for Control and Evaluation of the new scenario
- Adjust and redesign: AIMS, AIK, Logic Model, and the generalized double diamond

- Collaborative Convergence Pyramid

In the end, the project was able to create engagement and continued resilience by listening to the results of those who are part of the new common space generated by this community as we all struggle to overcome the challenges and reduce the uncertainty of the larger society. Despite the end of the funding for the project and the challenges faced by the COVID-19 disruption, the schools continued the STEM clubs and the interest in STEM experiences.

11. Conclusions

All of these models: AMIS, AIK, Logic Model, USP model Diamond Model and Double diamond were used to help in the design of the Collaborative Convergence Pyramid and development of our own NSF project that used the collaborative infrastructure to work towards the Convergence Research approach. Even as the research brought together a range of partners and developed the needed planning documents to generate the shared vision with shared goals and metrics, more was needed. Each of the partnerships that were explored both needed to align with our existing work but also allow room for adjustments and reworking. Even with effective leadership shared amongst all participants and effective communication strategies, more needed to be innovated over time. This leads to the last aspect of the Convergence Research approach. The tools and methods are supports that assist with the assembly of the infrastructure for collaboration and communication. However, the scenario is not a fixed point and so the world changes, as do the stakeholders and resources available. Leveraging things to effect change and employ the efforts of individuals is an ongoing issue.

This has led us to the understanding that being inter-disciplinary may attain integration leading to new developments. This can be taken further as innovation is sought as the work moves towards transcendence. In the case of large social innovation, however, without the strategy to sustain the work and be resilient through change, there is still a lack of convergence. The creation of new domains, common languages, and shared understandings leads to networks, communities of practice, and working systems that last and can evolve in response to the new challenges in our uncertain future.

This pyramid of new common vision, language, and commitment allows the addition of new members to the community and adaption to changes. In that case,

Convergence Research becomes another key method for attaining sustainable social innovation along the many different but interrelated channels of convergence.

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Abreviations

CD = Co- Discipline (Cross- and Across)
CoP = Community of Practice
e.g. = exempli gratia
et al. = and others
ID = Inter-Discipline
MD = Multi-Discipline
p./pp. = page/pages
TD = Trans-Discipline
UD = Uni-Discipline

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