# Creating a Culture of Transdisciplinary Learning in STEAM Education for K-12 Students

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*This paper presents an understanding of transdisciplinary education for K-12 STEAM students. Following four main transdisciplinary elements that can be exposed in the K-12 STEAM education curriculum were briefly explained: (1) attitudes of being transdisciplinarity, (2) transdisciplinary research aptitudes, (3) transdisciplinary thinking skills, (4) transdisciplinary integrated K-12 curriculum. The proposed transdisciplinary Innovation Platform (TIP) facilitates TD integration of science, art, math, social studies, technology, engineering, computational science, tools, and knowledge to meet the diverse needs of young students were also presented.*

**Keywords**: Transdisciplinary Research Process, transdisciplinarity with STEAM Education, transdisciplinary Innovation Platform, being transdisciplinarity, transdisciplinary research aptitudes, Transdisciplinary thinking skills, learning by Doing.

## 1 Introduction

There is an effort going on to turn the acronym STEM—which stands for science, technology, engineering, and mathematics—into STEAM by adding the arts. The STEAM is an exploration of the role of art and design in the creative inquiry process, in order to plan a transdisciplinary curriculum model that may be applied across disciplines (Costantino, 2018 [1]). Unique contributions of the arts to STEM education may be summarized as follows.

Civic participation and TD thinking skills around scientific issues can be most richly learned through involvement in the arts. The arts play important role in science and engineering and hold the knowledge and skills a person needs to participate actively in civic life. The arts can provide ways for both scientists and engineers to broaden their understanding of concepts from diverse disciplines and generate creative, innovative solutions to unstructured problems. In particular, the arts can help people develop skills such as visual thinking; recognizing and forming patterns; modeling; getting a "feel" for systems; and the manipulative skills learned by using tools, pens, and brushes are all demonstrably valuable for developing STEM abilities (Root-Bernstein, R. and Root-Bernstein, M., 2011, [2]).

The art provides students with problem-solving skills, innovative mindsets, communicative attitudes, and motivation. There have been experimental studies that indicate that intense exposure to art develops superior spatial-visual coordination and other basic skills (Shuster, 2014, [3]).

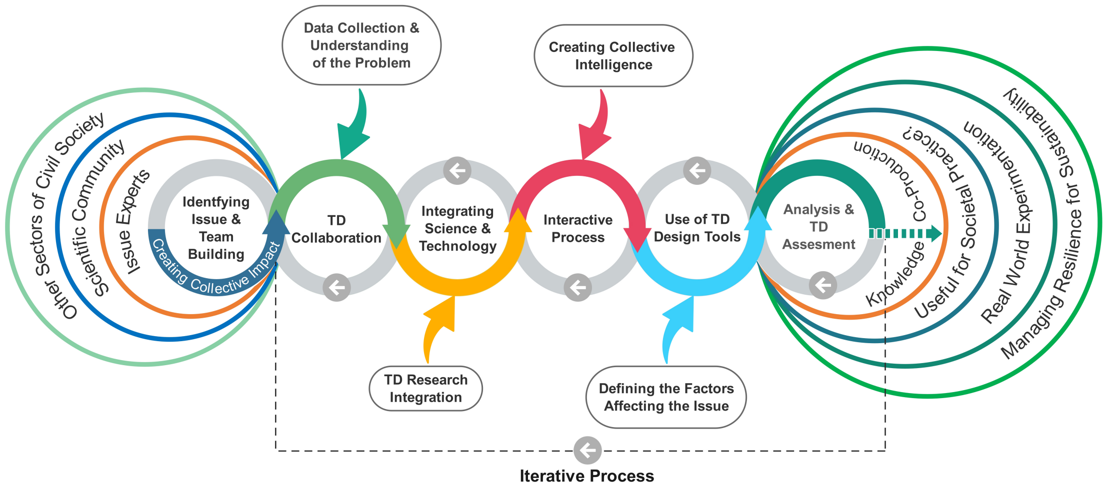


**Figure 1:** Transdisciplinary research process.

International Baccalaureate Organization (IBO) through Primary Years Program (PYP) provides transdisciplinary learning education to students between the ages of 3 and 12. There are over 1800 PYP schools worldwide (IBO, 2020 [4]; Gurkan, 2021, [5]).

## 2 Transdisciplinary Research Process (TRP)

A number of complex problems have begun to stand out as major concerns in the 21st century. Among them, the environment, climate change, immigration, hunger, water crises, world population, disease, and energy are some of the most serious issues affecting the world today. These issues that transcend disciplinary boundaries cannot be addressed by any one discipline alone: Transdisciplinary research (TDR) approaches can offer solutions to these challenges by providing new skills and tools aimed at creativity, innovation, and collaboration across knowledge fields.

Transdisciplinary research (TDR) is a new form of learning, practicing, and complex problem-solving process that includes participants from the scientific community, other sectors of civil society, and issue experts to tackle real-world problems (Lawrence, 2010, [6]). A new TDR process is defined as the integrated use of the tools, techniques, and methods from various disciplines (Ertas et al., 2003, [7]) and integrates disciplines to achieve a common scientific goal to address issues that are vaguely defined and reach across a broad swath of traditional disciplines. The phases of the proposed TD research process (see Figure 1) are: (1) identifying an issue and TD team building (creation of collective impact), (2) collaboratively understanding the research problem, (3) TD research integration, (4) developing collective intelligence through an interactive process, (5) defining the factors affecting the issue, and (6) analysis and TD assessment. If the results of the TD assessment provide useful research for societal practice, then the research outcome will have been implemented; otherwise, the TDR process will repeat itself. Finally, increasing resilience will impact sustainability in a positive direction.

## 3 Integrating Transdisciplinarity with STEAM Education

*Transdisciplinary skills in young students must be set in rich soil so that the seed can germinate and in time grow into a student of transdisciplinarians.*

**Prof. Ramamoorthy, past ATLAS Board member**

The Fourth Industrial Revolution, which includes developments in previously disjointed fields such as artificial intelligence and machine learning, robotics, nanotechnology, 3-D printing, and genetics and biotechnology, will cause widespread disruption not only to business models but also to labor markets over the next five years, with enormous change predicted in the skill sets needed to thrive in the new landscape (World Economic Forum, 2016, [8]).

"The impact of technological, demographic and socio-economic disruptions on business models will be felt in transformations to the employment landscape and skills requirements, resulting in substantial challenges for recruiting, training and managing talent." (World Economic Forum, 2016, [8])

Given the upcoming pace and scale of disruption, Fourth Industrial Revolution increasingly requires the education system to develop transdisciplinary skills and competencies to improve the intellectual capacity to deal with real-life problems. This kind of innovative educational program enables knowledge integration across diverse perspectives to prepare STEAM graduates for tomorrow's opportunities and challenges. The talent to manage, shape, and lead the changes underway will be in short supply unless we take action today to develop it.

As it is known, different social life, religious differences, pre-existing cultural habits, and access to learning opportunities through technology affected and lead to different education systems in different countries. "In spite of the enormous diversity of the systems of education from one country to another, the globalization of the challenges of our era involves the globalization of the problems of education (Nicolescu, 2011, [9].

Education, which is a part of the globalization process, is not something that can be done easily because of the issues we mentioned above– the disharmony that exists between the values and the realities of issues of each country will bring a different kind of contradiction and creates educational complexity. However, if we indeed want to live in a more harmonious and sustainable world, we cannot ignore the impact of global education on global sustainability.

In the world of these interrelated countries, what do we want? Is it a disaster to squeeze people of sense like COVID-19 into a different and complex situation? Is it to start a war and confuse world peace as it is now? The food shortage and seeing the famine in the world, to see millions of people die? water scarcity in the world is coming soon. Do we want to see people fighting for water instead of fuel?

The report to UNESCO of the International Commission on Education for the Twenty-first Century, clearly emphasizes four pillars of a new and different kind of education: learning to know, learning to do, learning to live together with, and learning to be – namely, educating students for life beyond the classroom. From this perspective, the transdisciplinary approach can make an important contribution to the initiation of this new type of global education that will have a positive impact on the attitudes and values of students and on the well-being and sustainability of our planet Earth.

Although the past decade has seen growing interest and investment in TD graduate education, undergraduate remains predominantly dependent upon narrow, disciplinary foci. To prepare students to become well-trained professionals, disciplinary programs must start integrating TD courses into the undergraduate curriculum (Ertas et al., 2015-A, [10]; Ertas et al., 2015-B, [11]; Ertas, 2017, [12]). Although researchers have become accustomed to working across disciplinary boundaries, the undergraduate classes offered by many universities have been the same for decades. Undergraduate students should master TD competencies and begin the process of becoming transdisciplinarians before they go on to graduate studies or start working.

It is encouraging that there are articles and examples of TD education integration into the K-12 curriculum, but it is also limited (Puig & Froelich, 2021, [13]; Wu, et al., 2020, [14]; Souto-Manning et al., 2019, [15]; Zaretsky, 2007, [16]). The need for TD education for K-12 students crosses disciplines to provide a skill set and confidence in young kids is one of the main objectives of this paper. As shown in Figure 2, the proposed four main transdisciplinary elements can be exposed in the K-12 STEAM education curriculum.

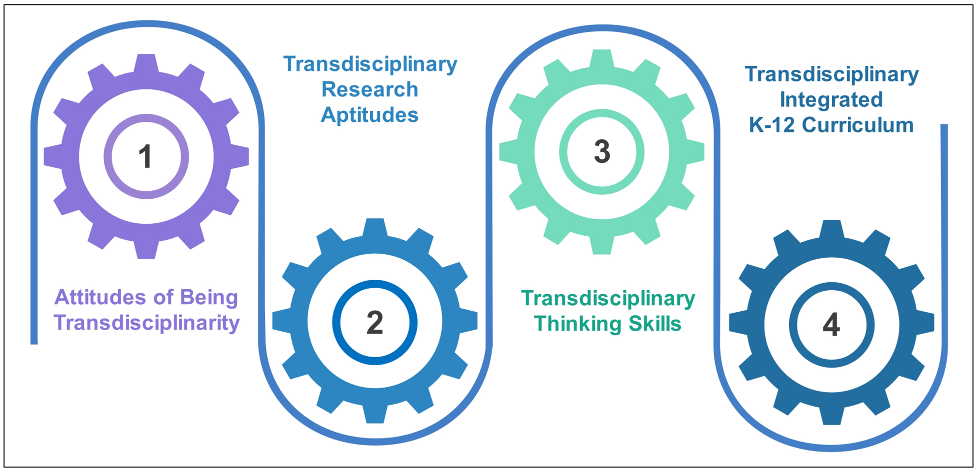


**Figure 2:** Proposed four main TD elements for TD K-12 STEAM education.

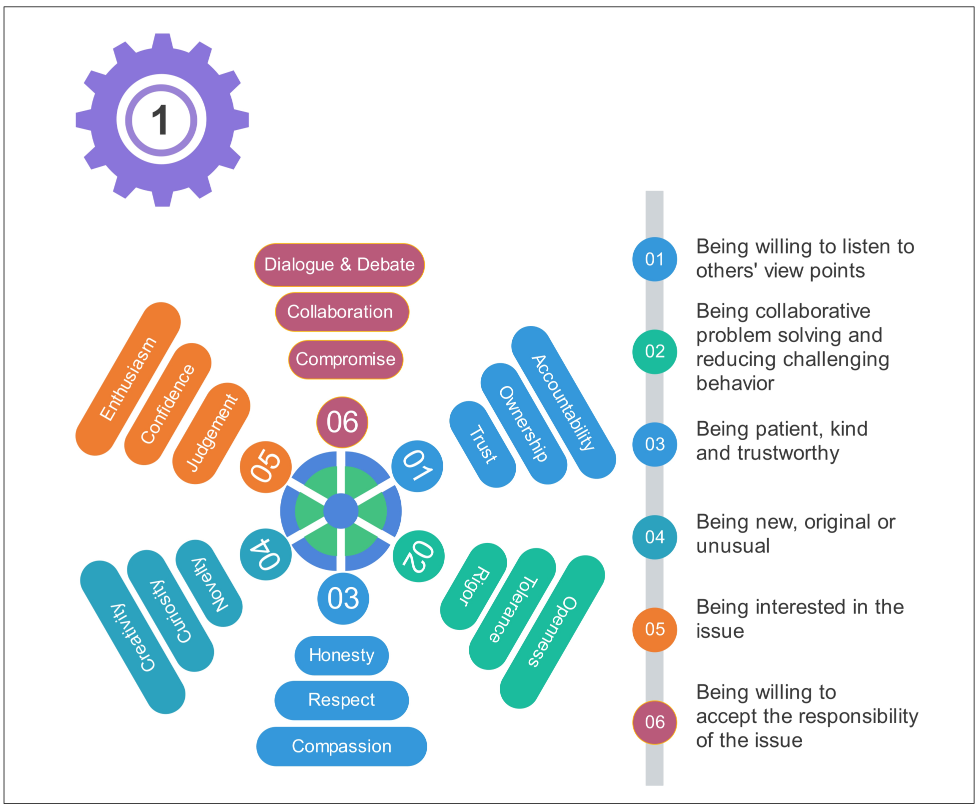


**Figure 3:** Attitudes of being transdisciplinarity.

## 3.1 Attitudes of Being Transdisciplinarity

Within the six categories, eighteen student attitudes are proposed that students should value and practice. These TD attitudes shown in Figure 3 are proposed to be exposed throughout the curriculum.

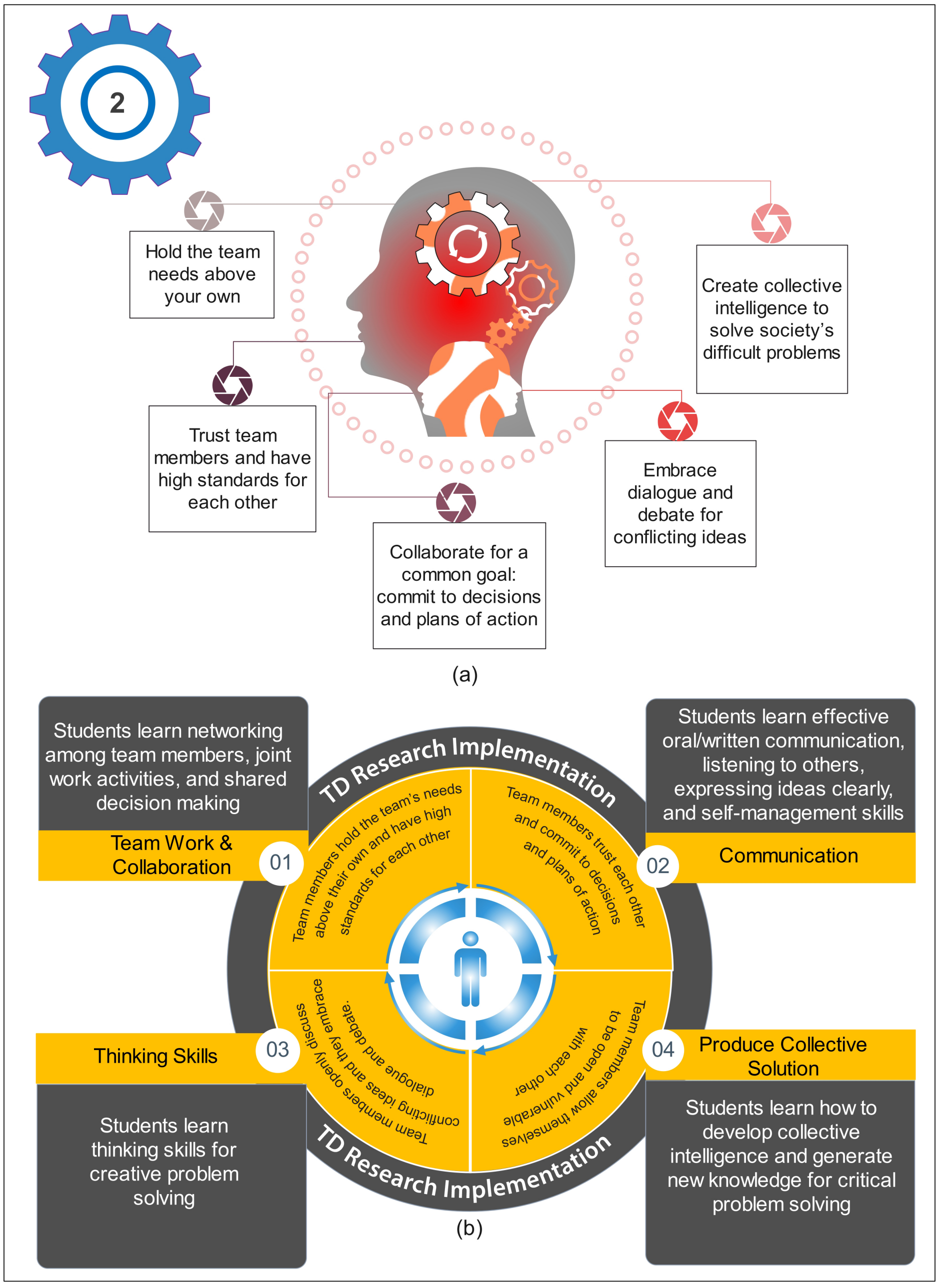


**Figure 4:** Transdisciplinary research aptitudes.

## 3.2 Transdisciplinary Research Aptitudes

There are five (promises) main transdisciplinary research aptitudes for TD learning (see Figure 4(a). In any TD research implementation, students will carefully follow those aptitudes. K-12 teachers should also understand the principles and five promises of TD research and show young students how to apply these principles in order to help every student succeed in TD research. Figure 4(b) shows the creation of excitement and confidence in young kids to design and develop problem-solving skills.

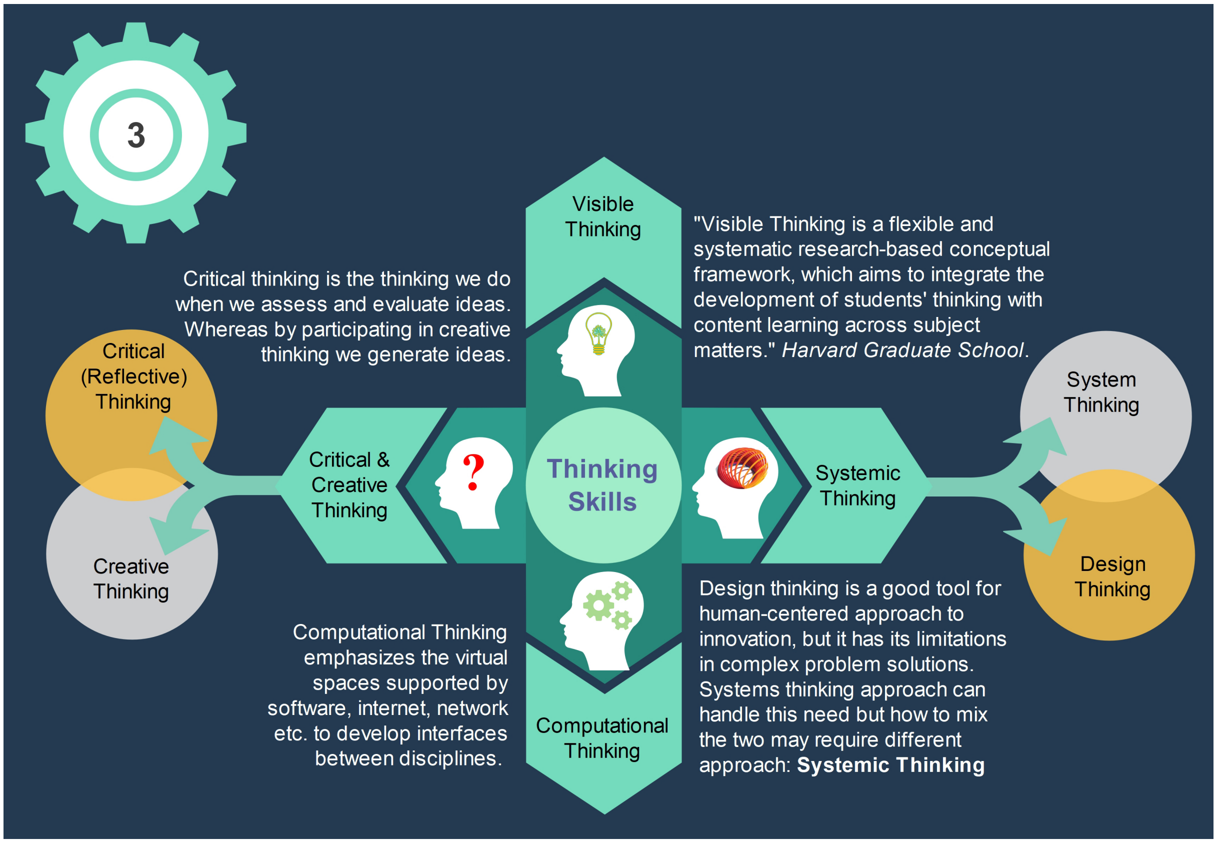


**Figure 5:** Transdisciplinary thinking skills.

## 3.3 Transdisciplinary Thinking Skills

The thinking skills are considered transdisciplinary–they are not specific to a particular discipline or field. Transdisciplinary thinking skills are summarized in Figure 5.

> "Thinking exercises can improve thinking skills. Think of your brain as a muscle...the more you exercise it, the stronger it gets. Mental exercise helps the brain to detect and identify patterns and relationships. It also improves memory and concentration. Classes in ways of thinking will also increase students' creative power and open their perspective on what's possible." (Bob Block, 2016, [17])

> "Transdisciplinary (TD) Thinking is one of the most powerful TD skills. It should be taught to all students at every level, as a foundational part of their education. Learning to think in multiple ways will advantage every student. Thinking, along with its sister skills, memory and concentration, imagination, intuition, curiosity and inspiration provide the access to the caverns of our minds" (Bob Block, 2016, [17]).

# 4 Transdisciplinary K-12 STEAM Project-Based Learning

Transdisciplinary Project-Based Learning engages and motivates students through hands-on transdisciplinary learning experiences. As shown in Figure 6, four core courses are built around TD innovation platform.

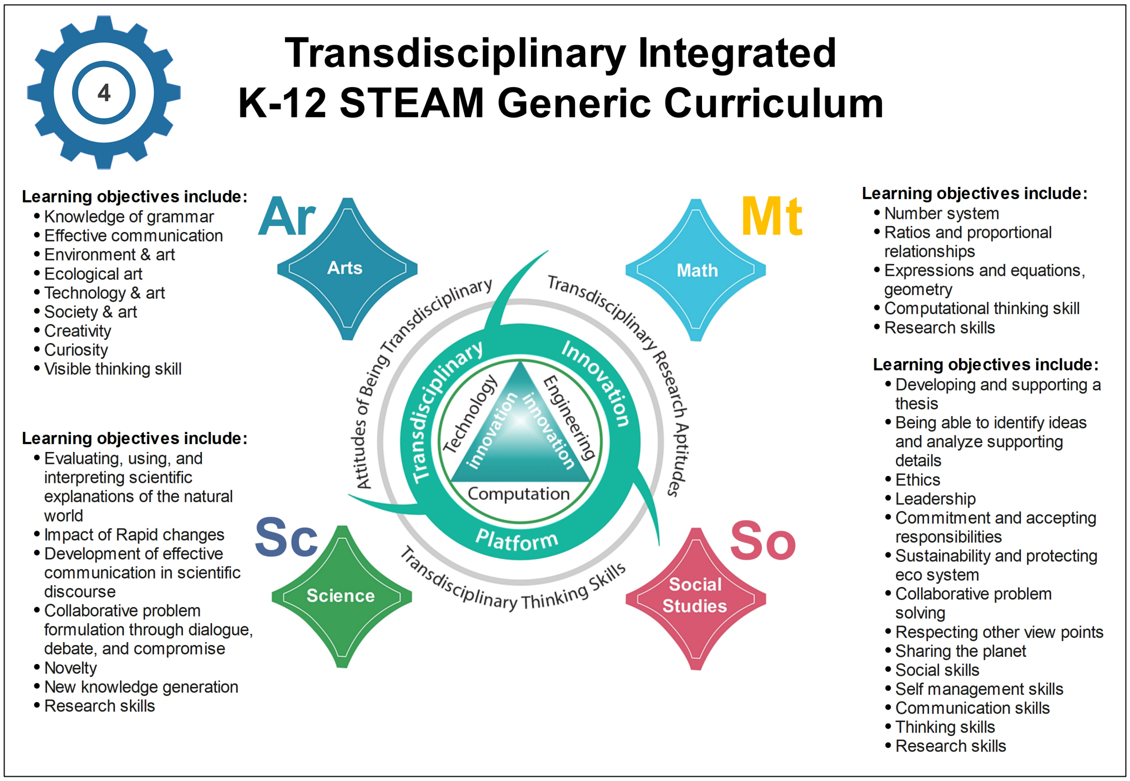


**Figure 6:** Transdisciplinary Innovation Platform (TIP).

Transdisciplinary Innovation Platform (TIP) facilitates TD integration of science, art, math, social studies, technology, engineering, computational science, tools, and knowledge to meet the diverse needs of young students such as cultural, intellectual, aesthetic, mental health difficulties, behavior, and emotional development, etc.

The main goal of the TIP is to create excitement and confidence in young students to develop innovative thinking and problem-solving skills. Within the TIP, we envision integrating TD skills (attitudes, research aptitudes, and thinking skills) and teaching young students TD concepts in new and different contexts such as those provided by TD project-based learning: engaging and motivating students through hands-on transdisciplinary learning practices.

Engineers use STEAM skills to create new or improved services and products that are more socially attuned–Engineering Innovation. It is important to note that introducing engineering design concepts to K-12 students is a crucial step in the integration of science, technology, engineering, art, and mathematics (STEAM) and the vehicle to encourage them to consider engineering as a career.

A Technological Innovation is a new or improved service or product whose technological features are considerably different than earlier versions. For example, virtual learning in K-12 is a justifiable innovation that resulted from the process of recombination of existing various technologies.

Computational Thinking (CT) is widely used for solving many academic and non-academic problems and encouragement for teaching computing in K-12 schools is growing in the U.S as well as in other countries (Enoch Hunsaker, 2022, [18]).

> "Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (Wing, J., 2011, [19].

Along with the power of technological methods, integrating computational thinking will help to develop innovative thinking and problem-solving skills in young students. CT emphasizes the virtual spaces supported by in-silico environments to develop interfaces between disciplines. CT not only would create highways between disciplines but also links them (via infrastructure) to capture ideas from many disciplines and create new or improved common platforms and roadways between them–*computational innovation.*

### 4.1 Progressive Education–Learning by Doing

Progressive Education is based on the principle, supported by John Dewey. Progressive education teaches children how to think rather than depend on routine memorization–learning by doing: it is inquiry and project-based. This concept is known as experimental learning which uses hands-on project-based learning that allows students to learn by actively engaging in activities that put their knowledge to use. Through this concept, a collaborative environment is created that requires teamwork, transdisciplinary thinking skills, creativity, and the ability to work independently (Progressive Education, [20]).
Progressive education programs have the following qualities:

- Emphasis on learning by doing–hands-on projects, experiential learning.
- Integration of entrepreneurship into education.
- Emphasis on TD thinking skills to solve problems.

### 4.2 Implementation

Although “FUN” projects will be assigned to young kids (K1-4), the following difficulties of the projects will be assigned to students working in small groups depending on the class level they are in (K5 to K-12).

**Easy Problems:** simple and very easy to understand but the solution could be creative.

**Difficult-Easy Problems:** can be achieved without great effort: experiencing few difficulties.

**Difficult Problems:** need more effort or skill to achieve, deal with, or understand.

**Complex Problems:** there is no straight way to a solution for complex problems–they have too many unknowns and too many interrelated factors that are constantly changing in unpredictable environments. Generally speaking, there are three kinds of complexity, namely, dynamic, generative, and social. A problem that is dynamically complex means that the cause and effect are far apart in space and time and therefore it is difficult to grasp from first-hand experience. A problem is generatively complex implying that it is unfolding in unfamiliar and unpredictable ways. A problem that is socially complex usually means that people involved see things very differently and could not come to a common ground.

## 5 Concluding Remarks

In this paper, the author proposed four main TD elements be exposed to young students in TD K-12 STEAM education as shown in Figure 2– attitudes of being transdisciplinarity, transdisciplinary research aptitudes, transdisciplinary thinking skills, and transdisciplinary project-based learning.

We need to prepare our young students with TD skills that help them to thrive and adapt to any profession, future challenges, or situations they find themselves in. The skills such as thinking skills, social skills, communication skills, self-management skills, and research skills are considered transdisciplinary–they are not specific to a particular area or discipline.

Transdisciplinary learning establishes a connection between subject matter to meaningful real-life contexts, allowing students to understand the topic much deeper–engaging young students in a variety of learning experiences that help them to learn how to apply their knowledge for different ways to solve a problem.

As Basarab Nicolescu asserts, the meaning of "Being Transdisciplinary is to face the challenges of the present world in all their complexity. We are facing a period of new barbarism... This new barbarism can lead, for the first time in history, to the total destruction of the human species. Transdisciplinarity has to be deeply and practically involved with the planetary and societal problems of today (Basarab Nicolescu, 2019, [21]).

Within the six categories, eighteen student attitudes are proposed that students should value and practice. These TD attitudes shown in Figure 3 are integrated in the K-12 STEAM curriculum (see Figure 6). The proposed transdisciplinary K-12 STEAM curriculum shown in Figure 6 is important because it integrates various subject matters around the TD Innovation Platform and creates connections through four TD elements between the four core courses to see and make connections between and among subjects–that is transdisciplinary learning.

Transdisciplinary learning experiences are placed on Transdisciplinary Project-Based Learning which engages and motivates students through hands-on real-life problems. Let's use the following hypothetical problem as an example.

### *Prevention of Plastic Water Bottle Pollution*

At the beginning of the TD project-based learning class, a series of lectures were given on plastic waste (pollution). Elementary school students were shown videos of how plastic waste impact the environment. Through lectures, students learn why plastic pollution is a serious issue of global concern (social studies). They learn the world is facing a plastic crisis–small plastic particles that attract toxic chemicals (science) are ingested by wildlife on land and in the ocean and contaminate the global food chain. Marine plastic pollution can now be found in all the world's oceans. A short lecture was also given on how disposable plastic water bottles are destroying our earth and new engineering solutions such as technologies that can recycle waste plastic–plastic water bottle waste goes into the ocean and kills over million marine creatures each year. To make the class interesting and fun, class lectures were made interactive and gives students more chances to engage with each other- teaching children to learn the importance of teamwork and collaboration (being transdisciplinarity).

*Then, let's assume that students were asked to find out how many plastic water bottles they used in a month at their homes and how they can prevent plastic water bottle pollution.*

The teacher used students' results to create a graph of plastic water bottle usage (math) and discuss the impact of plastic water bottle usage on the environment. Then students worked as a team to discuss the issue for solutions through collective intelligence (being transdisciplinarity). They presented and explain their rationale for their solutions and identify the following action plan:

- Don't use plastic bottles in your home
- Use water dispenser
- Replace disposable bottles with a reusable one
- Strat awareness campaign reducing plastic pollution by art

This would have been a great inspiring topic for elementary school students to learn–not to give up on their future and protect the planet that they will be living in; to develop a respectful relationship with each other; to dialogue, debate, and compromise. And most importantly they learn how to unite to solve a common global problem–being transdisciplinarity. Students' solutions to this problem were not surprising.

Through this case study, attitudes of being transdisciplinarity are partially implemented to bridge four core courses with transdisciplinary practices–integrating math, science, social studies, and arts. With this example, integrating transdisciplinarity with STEAM education was also accomplished by introducing engineering solutions to develop new technologies that can recycle waste plastic.

The future goal of this work is to use the information provided in this paper to develop a Global Transdisciplinary K-12 STEAM *educational tool box* to teach the next generation of young problem solvers that will have a positive impact on the attitudes and values of students and on the well-being and sustainability of our planet Earth.

> *Transdisciplinary skills in young students must be set in rich soil so that the seed can germinate and in time grow into a student of transdisciplinarians.*
>
> **Prof. Ramamoorthy, past ATLAS Board member**

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**Dr. A. Ertas**, Professor of Mechanical Engineering and director of the Academy for Transdisciplinary Studies at Texas Tech University, received his master's and Ph.D. from Texas A&M University. He had 12 years of industrial experience prior to pursuing graduate studies. Dr. A. Ertas has been the driving force behind the conception and development of the transdisciplinary model for education and research. His pioneering efforts in transdisciplinary research and education have been recognized internationally by several awards. He was a Senior Research Fellow of the ICC Institute at the University of Texas Austin (1996-2019), a Fellow of ASME, a Fellow of Society for Design and Process Science (SDPS), Founding Fellow of Luminary Research Institute in Taiwan, an honorary member of International Center for Transdisciplinary Research (CIRET), France, and a member of ASEE. Dr. Ertas has earned both national and international reputations in engineering design. Dr. Ertas is the author of a number of books, among them: Ertas, A. and Jones, J. C., *The Engineering Design Process,* John Wiley & Sons, Inc., first edition 1993 and second edition 1996; Ertas, A., *Prevention through Design (PtD): Transdisciplinary Process,* funded by the National Institute for Occupational Safety and Health, 2010; Ertas, A., *Engineering Mechanics and Design Applications, Transdisciplinary Engineering Fundamentals*, CRC Press, Taylor & Francis Group, 2011; A. Ertas, A., *Transdisciplinarity Engineering Design Process,* John Wiley & Sons, 2018. He has edited many research books specific to transdisciplinary engineering design, among them: Ertas, A., (editor), *Transdisciplinarity: Bridging Natural Science, Social Science, Humanities & Engineering*, ATLAS Publications, 2011; B. Nicolescu, B. and Ertas A., (editors), *Transdisciplinary Theory and Practice*, ATLAS Publications, 2013; Nicolescu, B., Ertas, A., (Editors), *Transdisciplinary Education, Philosophy, & Applications,* ATLAS Publications, 2014; Ertas, A., Nicolescu, B., S. Gehlert, S., (Editors), *Convergence: Transdisciplinary Knowledge & Approaches to Education and Public Health*, ATLAS Publishing, 2016; Nicolescu, B., Yeh, R. T., Ertas, A., (Editors), *Being Transdisciplinary.* ATLAS Publishing, 2019; Ertas, A., (Editor), *Additive Manufacturing Research & Applications*, MDPI Publishing, Switzerland. He has also edited/co-edited more than 35 conference proceedings. Dr. Ertas' contributions to teaching and research have been recognized by numerous honors and awards. He has published over 200 scientific papers and book chapters that cover many engineering technical fields. He has been PI or Co-PI on over 40 funded research projects. Under his supervision, more than 190 MS and Ph.D. graduate students have received degrees.