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Cognitive Strategies in STEM Education: Supporting the Development of Engineers' Multi- and Cross-Disciplinary Competence

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The Fourth Industrial Revolution (4IR) ushers accelerated pace of innovation with the digital technologies and computing advances that requires urgent upskilling and reskilling the workforce. An educational response to this urgent need compels Higher Education Intuitions (HEIs) to re-evaluate their programs to develop a STEM-literate workforce capable of making informed decisions given the complexities of today’s world and to open up opportunities to fill the growing need for STEM professionals. The objectives of combining multiple engineering approaches and technologies are to resolve real world problems, to provide different perspectives on real word complex problems, to create comprehensive research questions, to develop consensus definitions and guidelines, and to promote improved engineering services that address 21st century problems.

Reasoning modalities have been the subject of interest and debate for the past decades in engineering education and for STEM in general. This study attempts to understand the various thinking modalities for multi-disciplinary engineering students. We also question the appropriate thinking strategy for cross-disciplinary engineering technology students given the 4IR-induced evolving workplace. A comprehensive literature review of empirical articles is also provided, which is aligned with the research questions published in scholarly journals over the past two decades and reveals the state of scientific thinking on these topics. Preliminary results informs instructional pedagogies on multidisciplinary engineering and cross-disciplinary engineering technology programs to exploit the capabilities of the 4IR innovations.

Keywords: Multi-disciplinary engineering, cross-disciplinary engineering technology, cognition, critical thinking, design thinking, STEM curriculum.

1. Introduction

The Fourth Industrial Revolution (4IR) has been characterized by a range of new emerging technologies such as robotics, smartphones, new and cheap sensors, intelligent transportation, artificial intelligence (AI), the Internet of Everything (IoE), nanotechnologies and Big Data information feeds that are fusing the physical, digital and biological worlds. The impact of 4IR will have far reaching effects as it evolves with greater velocity, affecting various industries, including the interconnected global economies, Higher Education Institutions (HEIs) and society as a whole. Such major disruptions in every field are calling for a total overhaul of the existing systems and processes [e.g., 1; 2; 3]. Although it is still unclear on the overall impact that 4IR will have on the 21st century workforce and beyond, a few relevant questions are raised: What are the skills valued by future employers? What role does literacy have in employability of the 4IR workforce? Some prognosticators predict that “classical” skills and cognitive capabilities are potentially highly valued [e.g., 4].

Higher Education in the 21st century plays a critical role in modern societies as globalization, rising international competition and technological advances make growing demands for a better qualified workforce. One of the challenges faced by HEIs is to prepare the next generation workforce with skills that will sustain them for long-term jobs [e.g., 5]. While 4IR will bring significant changes, the value of human capital will lie in their cognitive capability and learning skills to seamlessly integrate with a digitalized workforce. Accordingly, education 4.0 is about preparing students to thrive in a transformative world by exhibiting creativity, innovation, a range of problem-solving skills, people management; being able to coordinate with other people, negotiation and reasoning flexibility [e.g., 6; 7]. High employability for graduates include creativity, originality and initiative, a range of thinking skills, innovation and originality, technology design and programming, system analysis and evaluation, and judgement and decision making [e.g., 5; 8; 9; 10]. Students who possess these skills have behaviors that are characterized by a pursuit of academic goals despite any setbacks through active learning and learning strategies [e.g., 11].

Thinking as cognitive processes arise from neurobiological processes in the brain [12]. Teaching and learning, at their most fundamental and mechanistic level, are neurological phenomena arising from physical changes in brain cells. The notion that learning and memory are neurobiological processes provides opportunities to explore how pedagogical techniques (e.g., problem-based learning, inquiry based, etc.) might harness these known neurological processes to promote the creation and retrieval of long-term memories [e.g., 12] and of new thinking patterns for engineering and STEM education in general. Learning is possible because the brain creates memories through altering the synaptic connections between specific neurons, stores them in connected ensembles of neurons, and retrieves them by reactivating those same neurons and connections [e.g., 12]. Thinking and reasoning strategies are important skills for employability in 4IR but have also long been an active research topic in cognitive psychology. Aided by computer simulation, studies report that human thinking is associated with a wide range of tasks such as learning and remembering, problem-solving, inducing rules, formulating concepts, and understanding natural language [e.g., 13 and references therein]. These human-centered cognitive skills have been identified as must-haves for employability in the 21st century. While some of the technological advances of 4IR can outperform humans in repetitive tasks, these technologies lack the ability to explain the reason behind the decision. Therefore, the value of human capital in 4IR is their cognitive skills and decision-making abilities which includes creative reasoning strategies and problem-solving, the ability to create new combinations of ideas, and setting goals [e.g., 14].

Because STEM literacy is poised to be a very important skill advantage of the 21st century, there is a general consensus that everyone needs to be STEM literate [e.g., 15]. Literacy in any field presumes a possession of knowledge in a specified area. Generally speaking, a literate person ought to have the elements of knowledge in the field of interest [e.g., 16] coupled with a range of skills, and the ability to invoke thinking processes to identify issues and then solve a problem at home, in school, or in the workplace [e.g., 17; 18]. Accordingly, literacy includes foundation cornerstone knowledge (information), capabilities (skills) and cognitive strategies (habits of mind and decision making) that enable hypothesizing, designing, implementation, troubleshooting, conversation, evaluation, and analysis [e.g., 19]. Such proficiency can be developed through innovative education that focusses on re-tooling the future workforce via pedagogy that supports new synaptic connections through the various thinking modalities of STEM.

The section on **thinking strategies in STEM** describes various thinking modalities across STEM fields. These include critical thinking, design thinking, innovative thinking, analytical thinking, and mathematical thinking. The section on **literacy across STEM domains** outlines the dimensions of literacy and followed by the description of the literacy spectrum across STEM domains as well as identifying interrelationships across STEM. The section on **pedagogical approaches on multi-, inter-, and cross-disciplinary engineering competence** presents learning pedagogies that play a significant role in developing competencies for 4IR engineers. We include a brief example of the potential application of pedagogy for cross-disciplinary engineering technology students in a capstone course on land development. The **summary and conclusion** section includes commentary on the cognitive strategies that promise a most impactful educational model for developing competency for 4IR engineers.

2. Thinking Strategies in STEM

Thinking is what humans do every day. Psychologists and scholars have developed many innovative approaches and theoretical perspectives through computer simulations to understand the complex processes in human thinking [e.g., 10; 11; 13]. These studies allowed questions such as can thought be trained? Many pedagogical theories have been developed to address this very question. A literature review of reasoning modalities that are applied in STEM education can shed light on how HEIs could renovate their curricula to provide graduates with cognitive strategies and decision-making capabilities to succeed in the 4IR workforce. The ability to think critically has become an important employment indicator in many branches of industry all over the world [e.g., 20; 21]. Therefore, the education of young people who are faced with situations in today’s technology-driven, problem-riddled world must be reoriented towards developing appropriate thinking, reasoning, and decision-making skills [e.g., 22]. Furthermore, the rapidly evolving and global field of STEM education has placed ever-increasing calls for interdisciplinary research and the development of new and deeper scholarship in and for STEM education [e.g., 23]. Creative and varied thinking skills are vital skillsets for employability in the 4IR workforce [e.g., 8; 24 and references therein].

In the subsections that follow, various thinking strategies gleaned from a literature review will be described and their application in the various STEM fields identified. Specifically, thinking modalities include critical thinking, design thinking, abstract thinking, innovative (or creative) thinking, analytical thinking, and mathematical thinking. This list is by no means exhaustive but it provides a framework by which to review the multiplicities of cognitive strategies used in STEM pedagogy and to provide guidance for appropriate cognitive strategies for multi- and/or cross-disciplinary engineer education.

Critical Thinking

Critical thinking (CT) includes the ability to identify the main elements and assumptions of an argument and the relationships between the elements, evaluating evidence, the ability of self-correcting, and then draw a logical conclusion based on the available information. The literature offers no unique definition on critical thinking but it conveys the meaning that critical thinking is the intellectual process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation or experience. Critical thinking is also connected with cognitive processes like reflection, reasoning, or communication as a guide to belief and decision-making. While a literature review of critical thinking yields a plethora of descriptors and a variety of definitions [e.g., 25], most authors include basic phases of critical thinking. Critical thinking involves metacognitive actions along several capabilities that goes beyond technical skills. Critical thinking also requires meaningful and reflective judgement which leads to better logical conclusions of arguments. Critical thinking or reflective judgment is required to solve ill-posed problems [e.g., 26].

Five phases of critical thinking include the trigger event, an appraisal, the exploration, developing alternative perspectives, and integration [e.g., 27 and references therein; 28]. In the first phase, *the trigger event*, unexpected events occur that result in a sense of “inner discomfort and complexity”. This means that the problem or situation arrests attention that makes an impression that warrants further attention. During the think phase, to be most effective, the students’ task must pique their interest and motivate them to pay attention to the concept under consideration [e.g., 12]. The second *appraisal* stage involves defining the problem and selecting criteria to judge solutions. In this stage the thinker appraises the situation with a focus on the nature of the problem, the identification and clarification of the problem, and a search for other situations with a similar problem. The third phase, *the exploration step*, involves looking for and testing new ways of explaining or dealing with the situation. The fourth stage, *developing alternative perspective*, involves selecting a solution to the problem that appears as an optimal fit. This is but one solution out of many although deemed the best at the present instance. The final stage, *integration*, focusses on the results of the decision where the solution in the previous stage is integrated into the thinker’s life. The solution may involve a change or it may involve a renewed commitment to an already existing stance [e.g., 27].

Based on the above description, critical thinking can be seen as a self-regulating process that comes from developing skills such as interpretation, analysis, evaluation and explanation; going beyond technical skills. It can therefore be considered a metacognitive process [e.g., 14 and references therein]. To re-iterate, the ability to think critically is a vitally important skill in the engineering workplace [e.g., 29].

Design Thinking

Design thinking (DT), as a model of thinking for engineering and engineering technology students, is taken as an iterative and dynamic approach that is end-user focused. Design thinking

(DT) first gained popularity in the 1960s and, since then, has been applied to problem solving within business, primary education, and medicine. The process involves five stages: discovery, interpretation, ideation, experimentation, and evolution [e.g., 30], which are targeted toward empathizing with end-users to uncover and design for their unmet needs.

The *discovery* step involves methods to gather information that enables problem identification and hypothesis generation. The *interpretation* step presents opportunity to transform the observations from the problem identification step into creating an actionable problem statement. The outcome during this step is a recasting of problem statement to make it more nuanced and specific than the original challenge because it now originates from newly uncovered needs. Next is *ideation*, a brainstorming activity, to clarify concepts. The *experimentation* stage involves prototyping to make potential solutions tangible, actionable, and testable. This stage offers early identification of an idea's strengths and weaknesses, understand how end-users respond to the idea, and then follow up to optimally align with their needs and facilitates opportunities to improve and refine the idea. Finally, the *evolution* stage involves updates/modifications to the proposed solution after implementation.

DT emphasizes a human-centered approach to problem identification and not solely on quantitative methods as taught through traditional educational experiences. A DT approach requires that the student/learner construct a meaningful presentation of a stakeholder's problem. The problem statement should therefore be fashioned to incorporate and explore a deeper understanding of the end-user's perspectives [31]. DT emphasizes qualitative methods and techniques for creating information from raw data.

Innovative or Creative Thinking

Innovative or creative thinking can be defined as the entire set of cognitive activities used by individuals according to a specific object, problem, and condition. Creative thinking refers to conceiving new and innovative ideas by breaking from established thoughts, theories, rules and procedures. It includes a type of effort an individual put toward a particular event and problem based upon the individuals' capacity. It is not about breaking things down or taking them apart, but rather putting things together in imaginative ways. Creative thinkers try to use their imagination, intelligence, insight, and ideas when they face problem-solving situations. Three main stages or dimensions of creative thinking are identified as *synthesizing*, *articulation* and *imagination* [e.g., 24 and references therein].

The first stage, *synthesizing*, includes various activities such as deducing an original result from small parts, presenting alternate and authentic suggestions to the solution of the problem in question or situation confronted [e.g., 24]. *Articulation* is the second phase in which the thinker combines old and new knowledge about the problem in order to construct unusual relationships that produce new and authentic solutions. This phase includes expanding the current knowledge with the help of the new knowledge and making thoughts concrete through imagination and use of materials. The *imagination* phase is focused on constructing relationships between valid and reliable thoughts, presenting flexible ways of thought with the help of imagination, and to come up with different insights during the idea producing process – *ideation*.

Creative or innovative thinking is not merely reserved for art-based activities such as dance, music, or drama. Creative thinking involves making choices and critical evaluations. The creative thinking process integrates both problem setting and problem-solving skills which culminates in meaningful solutions. While it is correlated to critical thinking and problem solving, innovative or creative thinking has become a basic resource of experts in engineering.

Analytical Thinking

Analytical thinking involves an element of inquiry on ill-defined problems with uncertain outcomes. Analytical thinking in STEM is about breaking information down into its parts and examining those parts for their relationships. It involves thinking in a logical step-by-step manner in order to analyze data, solve problems, and/or use information to make decisions. The thinking process involves abilities to (a) take apart a problem and understand its parts, (b) explain the functioning of a system, the reasons why something happens, or the procedures of solving a problem, (c) compare and contrast two or more things, or (d) critically evaluate the characteristics of something [e.g., 32].

Such conceptual understanding characterizes the students' ability to implement a new concept in an unfamiliar situation, to link a new concept to concepts already known, and to explain and draw conclusions using a new concept. Analytical thinking is a process of thinking before acting - which is a critical stage for a well-planned design. Accordingly, this kind of thinking can yield the creation of tools or useful things through the interaction among students' themselves and between students and instructor [e.g., 33].

Mathematical Thinking

Mathematical thinking is the use of mathematical techniques, concepts and processes to solve problems directly or indirectly. It is a dynamic and active process which seeks to understand patterns of complex structures that permeate the world around us and, at the same time, facilitates combining ideas [e.g., 33; 34]. Mathematical thinking is about making logical inferences in mathematics, to use ways of thinking to solve the mathematical problems, to use creativity to properly combine the ways of thinking to address mathematical questions, and to protect and understand the mathematical ideas [e.g., 25 and references therein].

Mathematical problem-solving enables students to gain experience in general mathematical strategies such as abstraction, expression, symbolization, generalization, proving, and posing new questions. Problem-solving in mathematics includes using the necessary information and mental processes as well as embodied activities such as gestures, and body movements [e.g., 35]. Mathematical thinking will take place when high-level thinking skills are needed such as generalization, estimation, customization, hypothesis generation, and assessment of accuracy.

In summary, revolutionary insights in cognitive psychology informs how humans approach problem-solving and their strategies on information processing. Through computer simulation, psychologists identified that information processing in humans involve structural components of short-term memory, long-term memory, and associated mechanisms [e.g., 13]. Table 1 summarizes the various reasoning modalities employed in STEM education. Engineering has the most variety of thinking modalities and technology has the least. Creativity and innovation are essential in the engineering design process. Researchers, academics, educators, and engineering organizations all agree that further improvement in engineering education is necessary to foster creativity [e.g., 10; 36]. Such a task appears daunting because instructors usually prefer traditional teaching styles by relying on a didactic approach rather than modern strategies calling for activity-based methods. Because it is more difficult for STEM pedagogy to master different thinking strategies in a passive learning environment, student's STEM learning must involve opportunities to react to practical situations and to feedback of any critical suggestions [e.g., 21].

The preliminary findings as represented in the table indicate that a variety of thinking strategies are generally not practiced across the STEM domains. From a practice perspective, although mathematical thinking is often assumed as needed in different STEM disciplines, improving students' mathematical thinking is traditionally left for educators and teachers in mathematics. It is thus not surprising that discipline-based educators and teachers are in pedagogical silos and hardly communicate to each other about students' thinking. One possible factor is that discipline-based thinking has traditionally emphasized the importance of a specific discipline which, in turn, made cognitive strategies in other STEM domains less visible.

Table 1: Preliminary literature review on thinking in STEM

Reasoning Domain	Critical	Design	Innovative	Analytical	Mathematical
Science	✓			✓	
Technology	✓				
Engineering	✓	✓	✓		✓
Mathematics	✓			✓	✓

STEM literacy highlights the vital connection between an educated STEM workforce and national prosperity. However, the STEM-literacy gap is widening - contributing to increasing STEM pipeline leakage with serious skills deficiencies for the 4IR workforce. Silos in STEM pedagogy stifles integration. Accordingly, educators should strongly consider alternative ways that allows their teaching and learning approaches to navigate crossing STEM boundaries [e.g., 37].

3. Literacy Across STEM Domains

Literacy broadly refers to familiarity with the enterprise and practice of a particular discipline [e.g., 38]. Literacy spans the lifecycle of the domain. The use of the term literacy has a deep history within the United States as it relates to improving people's abilities to listen, read, and write in the English language [e.g., 18]. The origin of the term literacy is *letra*, Latin for letter. Therefore, literacy originally referred to the capacity to recognize letters and decode letter strings. That definition has evolved over decades to where literacy is an amalgam of three major constructs namely knowledge of a particular field, the capabilities or skills to perform tasks as warranted by the situation or the condition confronted, and ways of thinking that inform decision making with successful outcomes.

Knowledge is an important attribute of literacy in a specified area [e.g., 16]. Knowledge can be acquired through various technologies (books, speech, and video), but skill, on the other hand, implies the utility of action such as to identify and/or fix simple mechanical or technological problems. Thinking, as another dimension of literacy, involves activating the mental processes in order to solve a problem at home, in school, or in the workplace [e.g., 17]. Students acquire a level of literacy from college course material through reading, listening, and writing. The course curriculums outline the body of knowledge that a particular program will develop. Accordingly, students' knowledge grows over the duration of the course or program. Knowledge gained is gauged through various forms of assessment tools.

Skill is a special ability that is not part of a reasonable person's ordinary equipment but which results from aptitude through special training and experience [e.g., 39]. A skill is considered a controlled activity (such as a physical action) that an individual has learned to perform. Skills are subject to objective thresholds. So, for example, badges awarded by scouting organizations signify the reaching of a pre-determined level of skill in a particular field [e.g., 19]. Similarly, students' skills development in a particular field are outlined in the curriculum and assessed against specific learning objectives. There are general skills (often called transferable skills) as well as domain-specific skills. An individual's skills proficiency can be judged by the results of tasks performed. It can be judged on the continuum from low to high.

Thinking, skill, and knowledge interact with each other to control students' career or vocational development. But literacy can also be thought of as having three interdependent dimensions: knowledge, capabilities, and ways of thinking and decision making [e.g., 40]. Literacy, then, is best conceptualized as including three dimensions of literacy that span the lifecycle of the domain (i.e., Arts, STEM, etc.).

Figure 1 is a conceptualization of the dimension of thinking along three orthogonal axes. This representation of literacy provides a framework in which to describe the literacies in the various STEM domains or fields. The reach along the *knowledge* dimension ranges from limited to extensive, the scope along the *capability* or skills dimension ranges from low to high and the range of *cognitive strategies* (i.e., ways of thinking and decision-making) range from poorly developed to highly developed. Along the *knowledge dimension*, we might expect a literate person to understand basic concepts and terms, such as systems, constraints, and tradeoffs; know something about the nature of a design and/or process; and appreciate that the specific domain/discipline shapes human history just as people shape the domain/discipline. As for *capabilities dimension*, a literate person ought to have a range of hands-on skills, be able to identify problems; and use a cognitive process to solve a problem at home, in school, or in the workplace. In terms of *critical thinking and decision making* (ways of thinking and acting), a literate individual would be expected to weigh available information about the benefits and risks, costs, and trade-offs in a systematic way and participate, when appropriate, in decision making. Of course, the schematic does not consider all of the complexities of knowledge production, capability or skills development, and the nuances related to habits of mind. Nevertheless, this schematic provides a framework to make sense of the potential mutual influences between the different dimensions of literacy. Therefore, we use this framework to describe the literacies in the various STEM domains.

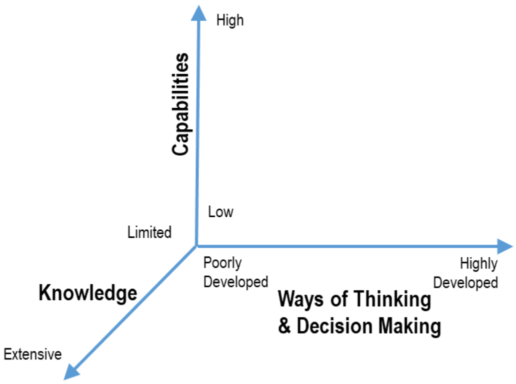

Figure 1: The Dimensions of Literacy

Science Literacy

Science literacy enables people to become and stay informed (and avoid being misinformed) on complex science issues [e.g., 40]. Gaining scientific knowledge is different for students than for the public. Students get scientific knowledge from textbooks and scholarly literature while the public access scientific knowledge from public libraries and the internet. College students learn scientific authenticity from seeking and reading scientific literature closer to the original source. The act of reading such high level scientific information helps support scientific inquiry, and therefore literacy [e.g., 19; 41].

Development along the knowledge dimension (see Figure 1) requires that a literate person grows in understanding of basic scientific terms, concepts and facts, such as understanding scientific practices (broadly speaking how scientist do science), identifying and judging scientific expertise, possess epistemic knowledge (i.e., how the procedures of science support the claims made by science), and the cultural understanding of science [e.g., 16]. This includes an appreciation of how sciences shape human history and at the same time how scientists shape their discipline. Along the capabilities dimension, a scientifically literate person ought to have a range of hands-on skills; be able to pose and evaluate arguments based on evidence and to draw and apply conclusions from such arguments appropriately [e.g., 42]; be able to describe, explain and predict natural phenomena. In terms of *cognition and habits of mind and decision making,* a scientifically literate individual would be expected to ask questions, manifest inquisitiveness, be open-minded, value the scientific approach to inquiry, and maintain a commitment to its evidence [e.g., 16].

Technology Literacy

The term "technological literacy", emerged in the early 1970's, conveyed the embodiment of knowledge and skills needed to function in a society dominated by technological innovation. Since the early 1990s, U.S. national leaders within technology education managed to position technological literacy as the fundamental goal of technology education for all students. The International Technology Education Association (ITEA) set out content standards for technology education and outlined precisely what student outcomes should be. Thus, they defined technological literacy as the ability to use, manage, assess and understand technology [18]. However, technology over the course of recent decades have significantly influenced and improved many areas of human life and work, as well as making mundane and repetitive tasks less burdensome [e.g., 21].

Along the knowledge dimension, we might expect a technologically literate person to understand basic technology concepts and terms, such as systems and components, constraints, and tradeoffs; know something about the nature of the design process; and appreciate that technology shapes human history just as people shape technology. Along the capabilities dimension, a technologically literate person ought to have a range of practical skills, such as using computer software and hardware, surfing the Internet, and operating a variety of appliances; be able to identify and fix simple mechanical or technological problems at home or work. In terms of critical thinking and decision making, a technologically literate individual would be expected to ask questions of him- or herself and others regarding the benefits and risks of technologies; weigh available information about the benefits and risks, costs, and trade-offs of technology in a systematic way; and participate, when appropriate, in decisions about the development and use of technology [e.g., 43; 44].

Engineering Literacy

Engineering is defined as a systematic and often iterative approach to designing objects, processes, and systems in order to meet the needs of society. The engineering design process typically begins with the specifications of needs or wants. Engineers identify constraints, analyze the features of systems and components, and devise plans for developing solutions. They understand the nature of the technology area to be modified, engage in systems thinking, work through engineering design processes, conduct maintenance and troubleshooting, and apply effective communication skills [e.g., 45; 46].

Along the knowledge dimension, we might expect an engineering literate person to understand basic concepts and terms, such as systems, constraints, and tradeoffs; know something about the nature of the engineering design process; and appreciate that the specific engineering domain/discipline shapes human history just as people shape the domain/discipline. Along the capabilities dimension, a literate person ought to have a range of practical hands-on skills including the ability to design under constraints, using tools and materials, capability with engineering graphics, prototyping (mock-ups), technical writing, computational methods and verbal communication skills; be able to identify and fix simple (mechanical or technological) problems, and use a specific cognitive process to solve problems at home or work. In terms of ways of thinking and decision making, an engineering literate individual would be expected to ask questions of him/herself and others regarding the benefits and risks of engineering design; weigh available information about the benefits and risks, costs, and trade-offs of technology in a systematic way; and participate, when appropriate, in decision making.

Mathematics Literacy

Mathematical literacy may be described as the means to have knowledge about, to understand, to exercise, to apply, and to relate to mathematics. Mathematics literacy focusses on the nature, role and meaning of symbols and on the rules for their usage. Math literacy includes having an opinion about mathematics and mathematical activity in a variety of contexts where mathematics plays or can play a role [e.g., 47 and references therein].

Along the knowledge dimension, we might expect a mathematically literate person to understand math concepts and terms, such as symbols and formalism which is about decoding symbolic and formal language, translating between mathematical symbolism and natural language, handling and utilizing mathematical symbolism, and transforming symbolic expressions. Such a person knows something about the nature of the math process and have an appreciation of how mathematics shapes human history just as people shape discoveries in mathematics. Along the capabilities dimension, a mathematically literate person ought to have a range of skills such as the ability to decode, interpret, and distinguish between and utilize different representations of mathematical objects, phenomena, problems, or situations. In terms of cognition and decision making, a mathematically literate individual would be expected to be capable of solving problems in a variety of contexts where mathematics play or can play a role. Mathematical problem tackling/solving skill involves the ability to detect, formulate, delimit, and specify different kinds of mathematical problems and solve them [e.g., 47].

In summary, literacy involves the accumulation of facts and information, followed by the application of such acquired knowledge to solve a problem, plan, or decide, and then follow through to apply appropriate thinking strategies, perhaps in an interactive reflective manner, to arrive at the best solution to the problem. However, as seen from the preceding discussion, STEM literacies have overlaps and could be a cross-disciplinary skill and part of a solution. Scientific and technological literacy are interdependent. Scientific understanding is the basis of much of technology, and so it makes sense that a technologically literate person must know some science. On the other hand, engineering literacy has been considered synonymous with technology literacy in that the latter is focused on product and objects while the former is focused on actions and understanding the process of creating and designing technological artifacts or systems.

4. Pedagogical Approaches on Multi-, Inter- and Cross-Disciplinary Engineering Competence

Pedagogical theories on learning and teaching have been investigated for several decades to inform practitioners on best practices regarding engineering and engineering technology education. Five distinct active learning pedagogies, i.e., project-based, problem-based, inquiry-based, case-based, and discovery-based, offer a learner-centered approach to student success [e.g., 53]. There is however, a strong dissonance between each pedagogy’s theoretical underpinnings and implementation realities [e.g., 54; 55]. Accordingly, traditional education and instructional models have developed in pedagogical silos. Traditional engineering pedagogies focused on domain-specific thinking. Domain specific thinking is often characterized in terms of its disciplinary content but can involve more general cognitive components. For example, an engineer’s thinking is scarcely only engineering (the knowledge component). It can share possible common elements with a technologists’ thinking. The same reasoning applies to students’ thinking in specific STEM disciplines. Preliminary results from Table 1 suggest there are many components of thinking that might be shared across a particular STEM discipline, which prompts the general question on how much thinking is domain-specific, how much is domain-general, and how much lies in-between.

Proponents of integration-based pedagogy often argue that interdisciplinary projects achieve a higher level of integration than multidisciplinary projects that merely concatenate disciplines [e.g., 56 and references therein]. *Interdisciplinarity* emphasizes the integration of disciplinary perspectives of a STEM domain – meaning that within an interdisciplinary model teachers and students inform each other’s perspectives and compare results through a transfer of knowledge across disciplines [e.g., 53 and references therein]. Such integration often leads to the creation of an entirely new discipline; for example, geomatics emerged this way. Even though members from different fields are contributing to the process, they are still grounded in their root disciplines.

Multidisciplinarity concatenates disciplines or their respective components within a STEM domain of field. In a multidisciplinary context, education consists of team teachers and students collaboratively learning from different fields while examining a similar, broad question. They may come together at various points in the process, but for the most part they examine a similar topic of interest from their own disciplinary lens, reach their own conclusions, and discuss their conclusion to their respective audiences.

Crossdisciplinarity mode aims to blend different perspectives in order to understand STEM problems and question their complexity rather than just addressing separate pieces of them. Crossdisciplinarities involve the application of theories, concepts, or methods across disciplines within a STEM domain with the intent of developing an overarching synthesis. In cross-disciplinary learning, the subdisciplines do not contribute components, but rather provide settings in which to test the transdisciplinary concept, theory, or method. It allows teachers and learners to transcend and operate outside the boundaries and cultures of their specific STEM disciplines in order to capture new realities, engage in cross-boundary communications styles, and address multilevel determinants [e.g., 53; 54].

Boundary crossing in integrated STEM education is described as crossing knowledge boundaries [37]. In the context where individual domains of S.T.E.M. have their own peculiar knowledge practices and reasoning modalities, boundary crossing can be mediated by boundary objects. Instead of seeing a STEM boundary as an obstacle, it should be viewed as a potential for learning since a boundary contains common pedagogical constructs and concerns on both sides of the boundary [e.g., 37]. A key to boundary crossing requires mediating objects to bridge the various disciplines' pedagogical content knowledge areas and gaps. Boundary objects articulate meaning and address multiple perspectives. They allow different groups to work and learn together based on a back-and-forth movement between ill-structured use in cross-site work and well-structured use in local work [56]. Boundary crossing involves the use of dialogical processes of learning pedagogies.

Table 2 shows the results of a literature review on the five learning pedagogical models and the corresponding thinking modalities in STEM. The preliminary literature review suggests that problem-based learning models is highly favored for all thinking modalities discussed above.

Table 2: Pedagogical Models on Active Learning and Thinking Modalities

Learning Theory **Thinking Modality**	**Problem**	**Discovery**	**Inquiry**	**Project (Experiential)**	**Case**
Critical Thinking	✓		✓	✓	✓
Innovative Thinking		✓			
Design Thinking	✓			✓	
Mathematical Thinking	✓				

Four dialogical processes have been proposed to traverse content knowledge boundaries [e.g., 37]. These dialogical phenomena include a) *identification* – meaning to delineate how things differ from another practice, b) *coordination* – meaning to communicate the connections between diverse practices, the efforts of translation between different worlds, and the operational routines that allow traversing STEM boundaries, c) *reflection* – the possibility to look at oneself through the eyes of other worlds, recognizing the differences between the practices and formulating new distinctive perspectives which thereby enriches one's identity beyond its current status, and d) *transformation* – meaning to confront different practices while recognizing a shared problem space as mediated by the boundary crossing object [37].

These boundary crossing processes are feasible although heterogeneous STEM domains involve different but sometimes overlapping pedagogical content knowledge boundaries. However, interdisciplinary boundary crossing should be less complex. Boundaries within the engineering domain of STEM are highly permeable so that boundary crossing may not be as arduous where all four dialogical phenomena should be used. We consider the first two dialogical phenomena as a starting point for problem-based leaning in engineering. Engineering competence can be achieved through problem-based pedagogy that purposefully involves the main STEM cognitive strategies for problem solving. Competence as a result of inter-, multi- and cross-disciplinary engineering pedagogy is doable through problem-based learning that occurs in an interactive learning environment. Boundary crossing is an important aspect in engineering pedagogy in order the development of inter-, multi- and cross-disciplinary competence in engineering students as they prepare to be productive in the 4IR workforce.

We investigated the merits of developing cross-disciplinary competence in a capstone course on land development of a 4-yr university engineering technology program. Students were tasked to propose a subdivision design of an 80-acre site located in a rural community. The cross-disciplinary project involved design thinking, established in engineering literacy, creative thinking to include diversity, equity and inclusion (DEI) principles in land development projects, critical thinking for understanding surface water runoff and drainage, and mathematical literacy on the open channel cross-section geometries and computations for runoff containment. The project required scientific literacy to incorporate computation of open channel flow for effective storm water runoff management. Mathematical literacy was required to determine the best geometric shapes for open channels storm water drainage and reservoir volume computations. The instructor aimed to include dialogical processes of coordination to facilitate boundary crossing among the various disciplines. Students successfully exploited their scientific literacy to carry out drainage computations for open channel flow using Manning's equitation. Students invoked mathematical thinking on the various geometric shapes of open channels and reservoir volume computations that could support water drainage and containments. This may be attributed to the high level of calculus requirement of the degree program. However, students struggled to invoke creative thinking as they aimed to include DEI principles in their site development proposals. While the overall outcomes of cross-disciplinary project suggest moderate improvement over traditional teaching and learning from previous years, this case study recommends significant gains for student exposure to cross-disciplinary pedagogy.

We differentiate between literacy and competence. Individuals may be very competent in the use of one or more specific technologies but may not be technologically literate. Although literacy includes an element of hands-on ability, this does not necessarily imply a high level of (technical) skill. Black's Law dictionary defines competence as "a basic or minimal ability to do something" and competency as "…the mental ability to understand problems and make decision" [39]. Competencies refer to the ability or capacity of an agent to act with information and knowledge combined with capabilities to address a given situation appropriately. Such knowledge or information can be in the form of symbols, graphs and diagrams or pictures. Therefore, we do not use the terms 'competency' and 'skill' interchangeably in this context. A skill is considered a controlled activity (such as a physical action) that an individual has learned to perform and its proficiency level pre-determined in a particular field [e.g., 19].

Educational achievement signals the level of knowledge attained in a particular field. While competency is understood as a continuum and typically unobserved latent characteristic, educational qualifications, along with receiving a formal diploma, certificate or an academic title, manifest thresholds or steps in the educational career trajectory. We conjecture that knowledge and capability are two enablers of competence.

Figure 2 shows how we conceptualize competence schematically as a three-dimensional space curve within the framework of the three major components of literacy – knowledge, capabilities and ways of thinking and decision-making. The purpose is to graphically demonstrate that the degree of competence depends on a multiplicity of factors including extent of knowledge acquisition, level of skill or capabilities, and the stage of cognitive development and decision-making skills.

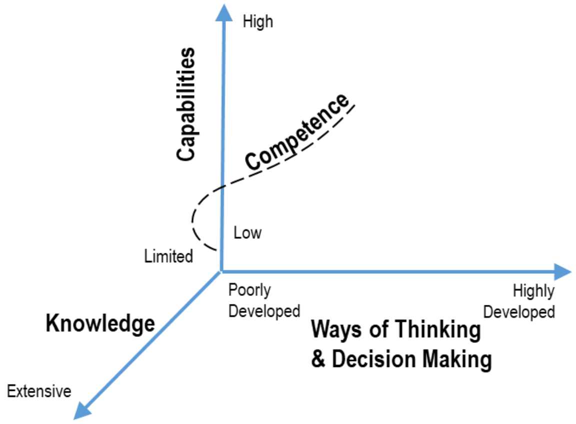

Figure 2: Conceptual schematic of competence in relation to the dimensions of literacy.

Basic competencies result from cumulative processes of knowledge acquisition that are moderated by reasoning ability. Many of these processes are facilitated, but not limited to, formal education and galvanized in the workplace and societal life [e.g., 48]. The more opportunities for knowledge acquisition are provided and used by an individual, the higher the level of basic competencies is achieved. Competency development is through experience and engagement in literacy practices, which extends far beyond formal education. Competency formation takes place through informal learning or through primary socialization within socioeconomic and cultural contexts [e.g., 48]. Finally, competency acquisition continues through the life course especially through work experience, opportunities for skill use, as well as deliberate efforts of life-long learning [e.g., 50]. Others view competence as subjective because competencies evaluations are based upon subjective judgements by another human being (or beings) who observe knowledge, skills and behaviors [e.g., 50; 51].

Discipline-specific competencies in STEM education is generally measured in large-scale assessments schemas. Discipline-specific competencies can be viewed as closely related to general cognitive ability [e.g., 50]. Hence, competence is related to the ability to improvise. Moreover, competence develops as a result of learning and not in a spontaneous manner [e.g., 52].

5. Summary and Conclusion

HEIs are tasked to prepare graduates with relevant STEM literacy and competence to successfully participate in the 4IR workforce. Our literature review provides new insights in how humans approach problem solving and their strategies on information processing. Thought and thinking patterns can be trained, and therefore we advance the notion that educators need to seek and implement alternative pedagogical theories in order to prepare engineering graduates with the requisite competence in order to successfully participate in the 4IR workforce.

The preliminary findings indicate that all types of thinking strategies are not shared across STEM. It is thus not surprising that pedagogical silos pose educational boundaries for interdisciplinary studies. As a consequence, discipline-based thinking has traditionally emphasized the importance of a specific discipline and made other cognitive strategies less visible. Our findings encourage further investigation on the potential to strengthen inter- and cross-disciplinary engineering education. Overarchingly, STEM literacies have overlaps and at these intersections could create a cross-disciplinary skill and part of a solution. STEM literacy, as a multistep reflective process, is a highly recommended skill for the 4IR workforce as it benefits both the individual and the nation as a whole through social-economic advantages and personal efficacy. Employability of individuals will be highly dependent on STEM literacy and complemented by their demonstrated track record on competence. Competence of engineering graduates is predicated on their exposure to innovative pedagogy. Despite the major technological and educational disruptions coming from 4IR in the future, an innovate engineering pedagogy that is flexible and agile to adapt and traverse STEM domain boundaries will prepare an engineering workforce that is able face future challenges and solve technological problems successfully. This means that human capital will become elevated above machines because of their cognitive skills and in their ability to seamless integrate with the 4IR workforce.

Reference

[1] K. Schwab, The Fourth Industrial Revolution: what it means, how to respond, World Economic Forum, 2016. Available at https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab. [Accessed February 2022]

[2] S. Chakravarty, How is 4IR creating new opportunities in geospatial industry? Geospatial World – Advancing Knowledge for Sustainability, January 15, 2018, Available at https://geospatialworld.net/article/how-is-4ir-creating-new-opportunities-in-geospatial/. [Accessed on March 2022]

[3] K. Allmann and G. Blank. Rethinking digital skills in the era of compulsory computing: methods, measurement, policy and theory, Information, Communication & Society, 2021, V24 (5), 633-648, 2021

[4] M. F. J. Fox, B. M. Zwickl, and H. J. Lewandowski, Preparing for the quantum revolution: What is the role of higher education? *Physical Review Physics Education Research* 16, 020131 (2020)

[5] U. Ramraj, F. Marimuthu, Preparing Undergraduate Learners with Skills Required by a Transformative Work Environment, *International Journal of Higher Education* Vol. 10 (1), 287-294, 2021

[6] A. Gray, World Economic Forum Report. The 10 skills you need to thrive in the Fourth Industrial Revolution, 2016. Accessed from https://www.weforum.org/agenda/authors/alex-gray. [Accessed on March 2022

[7] M. R, Cabrita, H. Safari, and M.P.M. Dueñas, Preparing for Education 4.0: Skills Facing Economic, Social and Environmental Challenge. *International Journal of Innovation, Management and Technology*, 11(1), (2020). https://doi.org/10.18178/ijimt.2020.11.1.872

[8] F. Mohd Kamaruzaman, R. Hamid, A.A. Mutalib, M.S. Rasul, Comparison of Engineering Skills with IR 4.0 Skills, *International Journal of Online and Biomedical Engineering* (iJOE) Vol. 15, No. 10, 15-28, June 2019

[9] C. P. Dwyer and A. Walsh, An exploratory quantitative case study of critical thinking development through adult distance learning. Educational Technology Research and Development, 68, 17–35, 2020. Available at https://doi.org/10.1007/s11423-019-09659-2. Accessed March 2022.

[10] K. O. Sokolov, I. A. Sergeicheva, M. I. Sokolova, Innovative thinking development in engineers. *Journal of Physics: Conference Series*. 1515. 022012, 2020. Available at DOI:10.1088/1742-6596/1515/2/022012

[11] S.M. Stehle, E. E. Peters-Burton, Developing Student 21st Century Skills in Selected Exemplary Inclusive STEM high schools. *IJ STEM Ed* 6, 39, 2019. https://doi.org/10.1186/s40594-019-0192-1

[12] M. T Owens, K. D. Tanner, Teaching as Brain Changing: Exploring Connections between Neuroscience and Innovative Teaching. *CBE Life Sci Educ*. 2017;16(2): fe2. doi:10.1187/cbe.17-01-0005

[13] Y. Li, A. H. Schoenfeld, A. A diSessa, "Design and Design Thinking in STEM Education," *Journal for STEM Educ. Res* **2,** 93–104, 2019. [Online] Available at https://doi.org/10.1007/s41979-019-00020-z

[14] M. Nussbaum, C. Barahona · F. Rodriguez, V. Guentulle, F. Lopez, E. Vazquez-Uscanga, V. Cabezas, Taking Critical Thinking, Creativity and Grit Online, *Education Tech Research Dev* , 69, 201–206, 2021 https://doi.org/10.1007/s11423-020-09867-1

[15] A. Zollman, Learning for STEM Literacy: STEM Literacy for Learning, School Science and Mathematics, V11 (12), 12-19, 2012. Available at https://doi.org/10.1111/j.1949-8594.2012.00101. Accessed February 2022.

[16] M. Hoepfl, Defining technological and engineering literacy, *Technology and Engineering Teacher TET*e, November 2020

[17] D. Ollis, G. Pearson, What is Technological Literacy and Why does it Matter? *American Society for Engineering Education*, 2006

[18] M. A. Rose, Perceptions of Technological Literacy among Science, Technology, Engineering, and Mathematics, Journal of Technology Education Vol. 19 (1), 35 - 52, 2007

[19] K. Klucevsek, The Intersection of Information and Science Literacy, *Communications in Information Literacy* V11, NO. 2, 2017, 354-365, 2017.

[20] M. Sellars, R. Fakirmohammad, L. Bui, J. Fishetti, S. Niyozov et al., Conversations on critical thinking: Can critical thinking find its way forward as the skill set and mindset of the

century? *Education Sciences*, 8(4), 205, 2018. Available at https://doi.org/10.3390/educsci8040205. Accessed March 2022.

[21] P. Brecka, M. Valentova, D. Lancaric, The implementation of critical thinking development strategies into technology education: The evidence from Slovakia, *Teaching and Teacher Education*, 109 (2022) 103555

[22] R A Kolvoord, Fostering spatial thinking skills for future citizens to support sustainable development, *Cultures of Science*, 2021, Vol. 4(1) 17 –24, https://doi.org/10.1177/20966083211024714

[23] Y. Li , A. H. Schoenfeld, A. A. diSessa, A. C. Graesser, L. C. Benson, L. D. English, R. A. Dusch, On Thinking and STEM Education, *Journal for STEM Education Research* (2019) 2:1–13. Available at https://doi.org/10.1007/s41979-019-00014-x

[24] B. Birgili, Creative and Critical Thinking Skills in Problem-based Learning Environments, *Journal of Gifted Education and Creativity*, 2(2), 71-80 December, 2015.Available at http://jgedc.org DOI: 10.18200/JGEDC.2015214253. Access March 2022.

[25] H. C. Çeliki and F. Özdemir, Mathematical Thinking as a Predictor of Critical Thinking Dispositions of Pre-service Mathematics Teachers, *International Journal of Progressive Education*, V16 (4), 2020, DOI:10.29329/ijpe.2020.268.6

[26] C. P. Dwyer, M. J. Hogan, I. Stewart, An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, 12, 43-52, 2014.

[27] C. L. McLean, Evaluating Critical Thinking Skills: Two Conceptualizations, *Journal of Distance Education*, V20, No 2, 1-20, SPRING 2005.

[28] R. H. Ennis, A taxonomy of critical thinking dispositions and abilities. In J.B. Baron & R.J. Sternberg (Eds.), Teaching thinking skills: Theory and practice (pp. 9-26), 1987. New York: W.H. Freeman.

[29] E. Cooney, K. Alfrey, S. Owens, Critical Thinking in Engineering and Technology Education: a Review, *American Society for Engineering Education*, 2008, AC 2008-1110:

[30] M. Gottlieb, E. Wagner, A. Wagner, and T. Chan, "Applying design thinking principles to curricular development in medical education," *AEM Education and Training*, V1 (1), 21–26, Jan. 2017. [Online] Available at https://doi.org/10.1002/aet2.10003. [Accessed Jan 5, 2022]

[31] M. A. Sahagun, R. Moser, J. Shomaker, and J. Fortier, "Developing a growth-mindset pedagogy for higher education and testing its efficacy, *Social Sciences & Humanities Open*, V4(1), 100168, 2021, ISSN 2590-2911, [Online] Available at https://doi.org/10.1016/j.ssaho.2021.100168. [Accessed Jan 15, 2022]

[32] R. Perdana, J, Jumadi, D, Rosana, Relationship between Analytical Thinking Skill and Scientific Argumentation Using PBL with Interactive CK 12 Simulation, International Journal on Social and Education Sciences, V1 (1), 2019, ISSN: 26887061 (Online)

[33] P. Chonkaew, B. Sukhummek, C. Faikhamta, Development of Analytical Thinking Ability and Attitudes Towards Science Learning of Grade-11 Students Through Science Technology

Engineering and Mathematics (STEM Education) in the Study of Stoichiometry, *Chem. Educ. Res. Pract*., V17(4) , 842-861, 2016

[34] A. H. Schoenfeld, Learning to Think Mathematically: Problem Solving, Metacognition, and Sense Making in Mathematics (Reprint), *J Education*, Volume: 196 issue: 2, page(s): 1-38, April 1, 2016

[35] C. Tran, B. Smith, M. Buschkuehl, Support of mathematical thinking through embodied cognition: Nondigital and digital approaches. *Cogn. Research* **2,** 16 (2017). https://doi.org/10.1186/s41235-017-0053-8

[36] C. Y. Long, B. Balakrishnan, C. P. Ying, K. Y. Yan, Effectiveness of Creative Thinking Module on Figural Creativity of Engineering Undergraduate in Malaysia, *International Journal of Higher Education* Vol. 9, No. 4; 2020. Available at URL: https://doi.org/10.5430/ijhe.v9n4p233. Accessed March 2022.

[37] A. Leung, Boundary Crossing Pedagogy in STEM Education. *IJ STEM Ed* 7, 15. 2020. [Online] Available at https://doi.org/10.1186/s40594-020-00212-9. [Accessed Jan 20, 2022]

[38] NAS, 2016, National Academies of Sciences, Engineering, and Medicine, Science Literacy: Concepts, Contexts, and Consequences (The National Academies Press, Washington, DC, 2016.

[39] B. Garner, Black's Law Dictionary. 8th ed. St. Paul, MN: Thomson/West, 2004

[40] E. L. Howel, D. Brossard, (Mis)informed about what? What it means to be a science-literate citizen in a digital world, Proceedings of the National Academy of Sciences Apr 2021, 118 (15) e1912436117; DOI: 10.1073/pnas.1912436117

[41] L. D. Purwani, F Sudargo, W. Surakusumah, Analysis of student's scientific literacy skills through socioscientific issue's test on biodiversity topics, 4th International Seminar of Mathematics, Science and Computer Science Education, IOP Publishing, IOP Conf. Series: *Journal of Physics*: Conf. Series 1013, 2018. doi:10.1088/1742-6596/1013/1/012019

[42] K. Martinez-Hernandez, C. Ikpeze, I. Kimaru, Perspectives on Science Literacy: A comparative study of United States and Kenya, *Educational Research International*, V4 (2), 25-34, April 2015. Available at Fisher Digital Publications: https://fisherpub.sjfc.edu/chemistry_facpub/4. Accessed Feb 2022

[43] J. Beynon (1993) Technological Literacy: where do we go from here? *Journal of Information Technology for Teacher Education*, 2:1, 7-35, DOI: 10.1080/0962029930020102, to link this article: https://doi.org/10.1080/0962029930020102

[44] M. Beynon, Computing technology for learning - in need of a radical new conception. *Educational Technology & Society*, 10 (1), 94-106, 2007.

[45] NAEP, 2018, Technology & Engineering Literacy Framework for the 2018 National Assessment of Educational Progress, National Assessment Governing Board, U.S. Department of Education

[46] T. J. Huffman, G. J. Strimel, M. Grubbs, Determining the Engineering Knowledge Dimension: What all High School Students Should Know to be Engineering Literate

(Fundamental), ASEE, 2018, Paper ID #21953, June 24-27, 2018, Salt palace Convention center, Salt Lake City, UT

[47] E. Geraniou, U. T. Jankvist, Towards a definition of “mathematical digital competency”. Educ Stud Math 102, 29–45, 2019. https://doi.org/10.1007/s10649-019-09893-8

[48] Y. Chae, S. Purzer, M. Cardella, Core concepts for engineering literacy: the interrelationships among STEM disciplines. *American Society for Engineering Education*, 2010, AC 2010-1287:

[49] R. Desjardins, Determinants of literacy proficiency: A lifelong-lifewide learning perspective. *International Journal of Educational Research*, 39(3), 205–245, 2003.

[50] N. Massing and S. L. Schneider, Degrees of competency: the relationship between educational qualifications and adult skills across countries. *Large-scale Assess Educ* V5(6), 2017. https://doi.org/10.1186/s40536-017-0041-y

[51] I. M. Castillo-Martínez, M. S. Ramírez-Montoya, Research Competencies to Develop Academic Reading and Writing: A Systematic Literature Review, *Front. Educ.*, 5, 18 January 2021, Available at https://doi.org/10.3389/feduc.2020.576961. [Accessed March 2022]

[52] P. Abrantes, Mathematical Competence for All: Options, Implications and Obstacles, *Educational Studies in Mathematics* 47, 125–143, 2001. *Kluwer Academic Publishers. Printed in the Netherlands.*

[53] L. R. Lattuca, Creating Interdisciplinarity: Grounded Definitions from College and University Faculty, 2003. *History of Intellectual Culture*, Vol. 3, 1, 2003. Available at www.ucalgary.ca/hic/ · ISSN 1492-7810. [Accessed March 2022]

[54] K. Hood Cattaneo, Telling Active Learning Pedagogies Apart: from theory to practice, *Journal of New Approaches in Educational Research*, V6(2), 2017, DOI https://doi.org/10.7821/naer.2017.7.237

[55] R. Kumar Shah, Effective Constructivist Teaching Learning in the Classroom, *International Journal of Education*, V7 (4), September, 2019

[56] S. F. Akkerman, A. Bakker, Boundary crossing and boundary objects. *Review of Educational Research*, 81(2), 132–169, 2011.