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Diversity, Equity, and Inclusion (DEI): A Conceptual Framework for Instruction and Learning the Geospatial Technology Competency Model (GTCM)

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Fields of research interest: a) Morphometrics: Searching source boundaries in potential field data. b) Space Weather: Ionospheric total electron content (TEC) characteristics and time series variability from GPS-time delays. c) Marine Geodesy: Coastal tide modeling and hydroacoustic mapping of aquatic vegetation and protected marine biological life. d) Engineering Education: Explore Spatial Literacy

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Diversity, Equity, and Inclusion (DEI): A Conceptual Framework for Instruction and Learning the Geospatial Technology Competency Model (GTCM)

Abstract: A wide range of geospatial literacy programs at colleges and universities have been developed based on the foundation pillars of the Geospatial Technology Competency Model (GTCM). Geospatial literacy programs at the associate and the baccalaureate degree levels may also seek accreditation so that graduates can become licensed professionals who will serve to protect the health and welfare of society. The Accreditation Board for Engineering and Technology (ABET) stipulates that the principles of diversity, equity, and inclusion (DEI) be explicitly covered in curricula. However, reports suggest that academic instructions fall short in student empowerment on DEI. This gap may be attributed to academics of the GTCM that follows traditional pedagogical models with a focus on technical skills without much consideration to address the power dynamics of unjust social structures.

This paper seeks to close this gap by investigating a framework for instruction and learning that informs DEI outcomes in association with the technical skills of the GTCM. Because geospatial literacy follows a similar pattern as information literacy, this paper investigates the applicability of the instructional framework used in information literacy to teaching the GTCM with DEI-informed outcomes. The framework for Information Literacy for Higher Education offers exploratory pathways for educators and institutional support departments to design instructional strategies that facilitate the transformation from information discovery through to knowledge creation. Following this paradigm, we expect that graduates from geospatial literacy programs will have gained significant technical skills and insight on understanding imagery, geospatial analytics, patterns and distributions of natural resources, boundary law doctrines, land development, and urban planning and be empowered to comment on social structures and institutional behaviors that infringe on the principles of DEI. This study contributes to the literature on education by seeking to understand factors on engineering pedagogy that supports DEI-informed learning outcomes for the GTCM.

1. Introduction

Diversity, equity, and inclusion (DEI) have been discussed in terms of social coexistence for individuals with disabilities [1], retention of underrepresented minority faculty [2], understanding student perception on social justice in urban planning [3], teaching empathy through critical service-learning [4], accessibility in the build environment [5], student recruit strategies [6], and engineering faculty hiring practices [7]. In contrast with these approaches, our paper addresses DEI by reframing it within the contexts of geospatial literacy teaching and learning that aims to empower students as potential change makers in their careers as geospatial professionals.

Society is grappling with several domestic issues including social injustices borne along by colonial-era unequal land distribution [8], poor land conversion projects and land use policies that enabled unhealthy ecosystems and unsafe urban environments (e.g. [9]). For example, blurring of rural-urban spatial and social boundaries, mobilized by urban sprawl, have induced new and unexpected changes in rural America at the expense of local solidarity and social cohesion [10]. Inner city neighborhoods are disproportionately inhabited by socially vulnerable populations where a multiplicity of environmental stressors compromise quality of life (e.g. [9, 11]). Transformation from agrarian to urban-industrial society urged by fiscal incentives from multinational corporation further galvanized social discords through cross-migration and intercultural conflicts [9, 10]. Government interventions on land redistribution (returning land unjustly taken) appear to lack sensitivity to rural livelihoods failing to help the poor meet the most basic of needs [12]. Root causes of these systemic inequalities are attributed to colonial-era social stratification and associated political will that secured long-run persistent wealth and asset imbalances for an elite few [8] but paucity of political clout and economic power that limit locational choices of vulnerable groups (e.g. [9]). Given societal changes in recent years college-bound students are often looking for a career that will fulfil their desire to "make a difference" in society. They consider STEM education as potential pathways. Organizations and industries globally are urging Higher Education Institutions (HEIs) to deliver "changemaking education" that equips students with skills to create social value in a rapidly changing world (e.g. [13, 14]). Furthermore, in 2017, business leaders at the World Economic Forum announced that the Fourth Industrial Revolution (4IR) will require "accelerated workforce reskilling" [15]. New educational approaches to address societal issues within systems include a radical retooling of STEM education with a deep consideration of ways in which new technologies, socio-political, and economic power dynamics impact society across all socioeconomic levels.

The IR4 high-tech innovations have enabled new biotechnology breakthroughs, renewable energy source, the Internet of Everything (IoE), and geosensing capabilities. In particular, innovation in geospatial technologies in the early stages of 4IR prepared a glut of remotely sensed imagery and maps to feed a voracious appetite for location-based information [16]. Geospatial technologies, such as Global positioning System (GPS), Geographic Information System (GIS), remote sensing (RS), Laser Scanners and the Robotic Total Station, supply location-based data and imagery for decision support across a multitude of industries from commercial applications to healthcare and the environment. While these emerging technologies are proving beneficial for a variety of reasons, their power has unleashed a kaleidoscope of imagery and maps revealing past practices and policies that worked social injustices, polarized society and that engendered modern societal discord within the built environment. Such issues raised during the 4IR will require HEIs to develop greater capacity for ethical and intercultural understanding, placing a high premium on "soft skills" in engineering education with adaptability to address injustices from past practices (e.g. [14, 15]). Competence and skill development for workers in the nascent multibillion-dollar geospatial industry is prescribed by the Geospatial Technology Competency Model (GTCM) [17]. Geospatial technology professionals work in a variety of specializations of the geospatial industry including surveying/geomatics and mapping, civil engineering, architecture, urban planning, forestry, and coastal and marine resource management, land development, and GIS mapping and analytics. These professionals and their associated professional organizations are well-positioned to contribute and inform social-ecologically sound policies (e.g. [18]) and foster intercultural understanding and respect for human rights.

Driven by the globally interconnected economies but disparate social-ecological systems, the shift in labor markets necessitates curriculum innovations at HEIs to emphasize the importance of soft skills for employability in engineering and other technical fields (e.g. [14, 19]). Various organizations and professional societies such as the National Academy of Engineering (NAE), the Accreditation Board for Engineering and Technology (ABET), the American Planning Association (APA), the National Society of Professional Engineers (NSPE), and the National Association of Colleges and Employers (NACE) recognized the need to address the societal changes and lend support to the goals for DEI-outcomes of professional degree programs at HEIs. Given the recent changes in the workplace (e.g. [14, 19, 20]) coupled with "wicked problems" [5 and references therein] in society that galvanize societal discord, it is evident that engineering curricula should include proficiency in a range of soft skills including diversity, equity and inclusion which must be learnt in the classroom and reinforced during professional practice [14, 21]. Relatively few studies report curricula that encourage student thinking and enacting DEI principles in real-life application [4]. Social entrepreneurship and social innovation education have been used to introduce DEI skills in the classroom. But critics of social innovation programs downplay its value because the focus is geared more on technical solutions and the role of HEIs within ecosystems rather than addressing the underpinnings of systemic issues and student learning outcomes [4]. Furthermore, stand-alone courses provide only a snapshot of DEI consciousness whereas an entire program designed with DEI-focused outcomes can potentially effect a sustained transformation in thinking and doing. Such holistic approaches can equip students with the skills and mindsets needed to enact sustainable and just solutions to complex challenges despite setbacks.

The GTCM was developed early in the 4IR primarily on technical skills without explicit attention to soft skill developments. ABET, a non-governmental organization, encourages college programs to support DEI practices so that program graduates can apply their skills in concert with the knowledge of the social, political, economic, and global context of their work [14]. We adopt the ABET definition for *diversity* which encompasses the range of individual differences including ethnocentric, socioeconomic, gender, biological, nationality, linguistic and cognitive differences, *equity* "… is the fair treatment, access, opportunity and advancement for all people, achieved by intentional focus on their disparate needs, conditions and abilities…", and *inclusion* "… is the intentional, proactive, and continuing efforts and practices in which all members respect, support, and value others…". The goal is to develop a framework around the GTCM that offers opportunity to equip students with the skills and mindsets to pursue sustainable and just solutions to complex challenges within the built environment. A DEI mindset includes behaviors such as social responsibility, motivation, disposition, creativity, and ethics [20]. Thus, the framework deliberately integrates soft skills along the continuum of GTCM technical skills development.

This paper is borne from a need to evoke discussion both "outward looking" from higher education to consider how geospatial engineering and technology interface with emergent phenomena of society at large but also "inward looking" that seeks guidance on the ideas, precepts, and principles on how to engage and empower students as next-generation geospatial professionals to effectively tackle difficult and seemingly intractable societal issues within the purview of their professional practice. **Section 2** gives a brief overview of the GTCM and its application in traditional curriculum development for geospatial engineering, science and technology programs. The overview offers a simplified perspective in terms of the competencies needed at the various skill employment levels within the geospatial industry. **Section 3** describes a framework for teaching and learning the GTCM that integrates soft skill development with adaptability to focus on DEI outcomes. The framework is constructed from Universal Design for Learning (UDL) principles, STEM-critical pedagogy, models for learning, and a feedback mechanism to assess and evaluation outcome attainment of the program goals. **Section 4** describes the key elements of the framework for DEI-informed GTCM programs. **Section 5** provides a discussion on the merits of the framework regarding how it leverages the GTCM skills and, at the same time, elevates students' mindset to not only have an ephemeral knowledge and understanding on pathways to tackle challenging problems but to espouse and give voice to DEI values while acting as change agents for social justice. **Section 6** is a summary and concluding remarks.

2. The Geospatial Technology Competency Model (GTCM)

The latter part of the 20th century witnessed an accelerated pace of innovation and advancement in location-based technologies that sparked a geospatial industry revolution [16]. Uses of location-based information found new applications in business, intelligent transportation systems, resource management, land use and urban development, and decision support for various civil infrastructures and assets. However, the term *geospatial* remains shrouded in mystery and its definition proves to be elusive. The term geospatial means different things to different people covering a wide spectrum from a science, a collection of tools, a profession, or an industry comprising a cluster of commercial activities related to location-based data [17]. Owing to this vagueness and lack of distinction, employers found it challenging to identify, recruit, and retain enough qualified workers. Accordingly, the United States Department of Labor Employment and Training Administration in 2010 commissioned a study to understand and define the range of skills needed for success in the geospatial industry. The result of the employer-driven study yielded the GTCM and depicted as a multi-tier pyramid of skills progression, starting with the entry-level worker to the specialists at the top tier [17].

Figure 1 shows a generalized GTCM as a multi-level triangle with entry level worker at the base and moving progressively upwards through to geospatial professional and expert at the apex. The triangulation scheme is also suggestive of the scale of employment, range of educational requirements and relevant skills. At the base, the large employment pool of low technical skill workers includes high school graduates with some post-secondary education. The top level employment ranks are relatively sparse. In the geospatial workforce in particular, the sparseness is related to the low number of education programs at university, low enrollment in existing university programs, and poor marketing and career pathway exposure to entry-level workers and college-bound STEM students. The triangular schema hovers above a rectangular base which represents foundation skills of personal effectiveness and general workplace competencies. This simplified representation of the GTCM shows stratified educational competencies of the GTCM starting at the technician level 1, followed by advanced technical skills acquired at 4-yr ABET-accredited programs in level 2, and then the licensed professionals and specialists at level 3. Side panels describes the related knowledge competencies for each level.

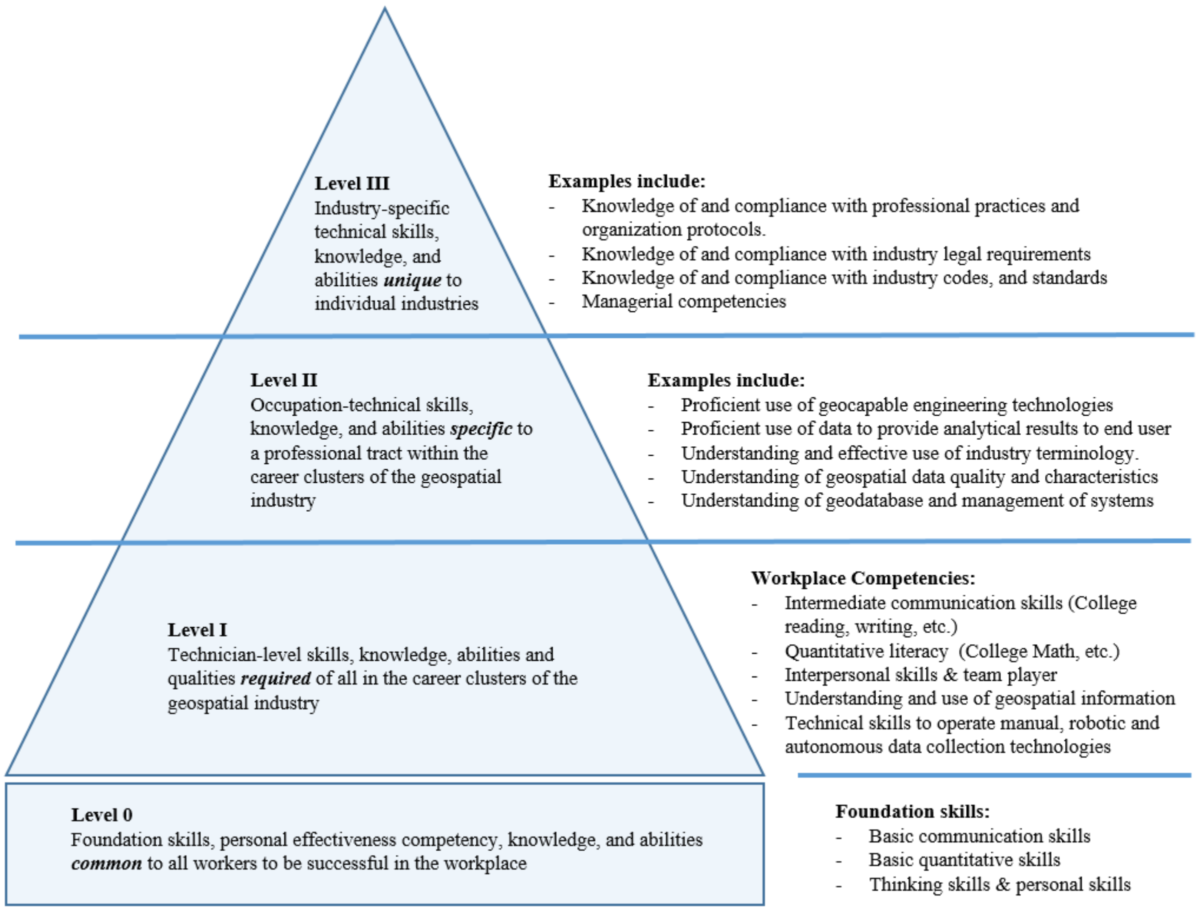

Figure 1: A generalized 2D representation of the Geospatial Technology Competency Model (GTCM).

Level 0 – foundational skills - describes the basic skills that are essential for most life roles that can be learned in the home or community and reinforced at school and in the workplace [17]. Such basic or foundation skills include personal effectiveness competency for general employability in the workplace. Foundational competencies specify general workplace behaviors and knowledge that successful workers in most industries exhibit.

Level 1 – technician skills - is the set of employability skills and abilities that are required of all entry-level employees. Competencies at this level include intermediate mathematical and writing communication skills, elementary problem solving, team skills, and mental agility needed to apply basic geospatial technical knowledge and be able to work with industry tools effectively. Moreover, the geospatial technical skills at this level involve elementary knowledge of positioning and data acquisition technologies. Such technical skills can be acquired through on-the-job training, apprenticeship programs, or an associates' degree from community colleges and reinforced in the workplace. Employees at this level exhibit skills in geospatial data production using technologies such as the GPS, RS, the Total Station, Terrestrial Laser Scanners and computer aided drafting technologies (i.e., AutoCAD or GIS). Such knowledge, skills and abilities enable workers to successful traverse lower tier job opportunities in the cross-cutting industries of the geospatial workforce (e.g. [17]). Master-level technical skills can be honed over time through personal dedication and goalsetting. Mature technicians of high caliber earn supervisory roles in small to mid-size companies.

Level 2 – technologist skills - comprises the set of industry-specific technical skills, academic knowledge, and abilities common to a technologist position within a geospatial career cluster. Skills include academic knowledge of data acquisition technologies, data quality, data analytics and modeling, and application of geospatial data science and software tools for adding value to geospatial data. The core abilities at this level involve the use of geospatial analytics tools to render valid and reliable information from geospatial data. Such skills are generally acquired from a 4-yr degree program and further galvanized in the workplace through interaction with professionals of the various sectors of the geospatial industry.

Level 3 – expert skills - denotes occupation-specific competencies and requirements at the licensed professional level. Competencies include analytical and technical skills for specific knowledge areas. The distinctive competencies at this top-most level of the triangle are acquired and developed through the licensure process for professionals and practitioners, advanced specialization certification, graduate school training in technical specializations of the geospatial industry (i.e., GIS, RS, Geodesy, etc.), or continuing education programs for practitioners. Graduates from ABET-accredited programs such as surveying engineering/geomatics or civil engineering programs go on to become licensed professionals and with additional work experience and training acquire specialization certification such as Geographic Information Systems Professional (GISP), Certified Flood Plane Manager (CFPM), Professional Planner (PP), or Certified Photogrammetrist (CP).

The GTCM standardizes programs with repeatable outcomes. It has served as a resource for educators to develop curricula, competency standards, and employment credentials. GTCM-based training programs have the traditional course outline that focuses on technical skills needed by the geospatial industry (e.g. [17]). Syllabi typically enumerate learning outcomes such as to demonstrate, describe, perform, identify, explain, and interpret a number of technical aspects of the GTCM. Thus, a variety of organizations including academia, professional societies, and workforce unions use the GTCM as a curriculum guide to offer degree, professional certificate, or apprenticeship programs in order to educate the next-generation geospatial workforce. Junior colleges, professional societies, and workforce unions utilize levels 1 and 2 of the GTCM to construct curricula for their respective technical training programs. University programs also take cues from the GTCM to specify general education requirements but then develop specializations as directed by the Body of Knowledge (BOK) of a particular domain of the geospatial industry. A BOK outlines the knowledge, skills, and attitudes necessary to be certified in a particular specialization. A discipline-specific BOK specifies a sequence of technical courses. Several specializations within the geospatial industry have a BOK for their particular discipline such as the Geographic Information Science and Technology (e.g. [22]), remote sensing (e.g. [23]), civil engineering (e.g. [24]), and others. The BOK for an ABET-accredited 4-yr surveying engineering technology/geomatics engineering or geospatial sciences program comprises five knowledge bases including positioning and measurement analysis, remote sensing technology and imagery, GIS, property boundary law, and land development [25]. Programs with ABET accreditation credentials ensure that graduates have met the educational requirements necessary to prepare for certification or licensure.

Rarely, if ever, do traditional syllabi in highly technical fields develop soft skills such as empathy, justice, equity and other human-centric qualities [14, 19]. The role and importance of soft skills versus hard skills are critical in well-balanced graduates in STEM fields (e.g. [5, 14, 20, 21]). Soft skills constitute a wide range of social and people skills, personal attributes, and self-management skills including communications, critical thinking and decision-making, interpersonal, negotiation, problem solving, self-confidence, teamwork and worth ethics [19]. The Architecture, Engineering and Construction (AEC) sector of the geospatial industry requests renovations to traditional STEM curricula [20] to include more soft skill development while retaining the training intensity on hard (technical) skills. While, the GTCM model addresses mainly the technical competencies, soft skills such as professionalism, ethics, dependability and reliability, interpersonal skills, and diversity, equity and inclusion are not explicitly incorporated. Inevitably, all ranks of geospatial workers during the course of their activities will intersect with social injustice in land use practices but be ill-equipped to effectively promote desired changes.

To address this shortcoming in the GTCM we look to the field on Information Literacy (IL) for guidance on how to incorporate soft skills within a program without exceeding government-mandated credit limits for STEM programs. Accordingly, a framework for instruction and learning GTCM-based curricula with DEI outcomes can be accomplished by incorporating UDL principles, STEM-critical pedagogy, and models for learning.

3. Integrative Components of Teaching and Learning the GTCM

US STEM curricula have credit limits mandated by state government agencies [26]. A typical ABET-accredited engineering or engineering technology program of 120 credit hours will specify that discipline-specific courses take up at least one-third but no more than two-thirds of the total credit hours of the program. Such programs would consume about 50-65% of the total credits leaving the reminder of 50 to 35% for scientific literacy and qualitative reasoning/Math, liberal arts literacy, social science literacy, and elective courses. This scenario leaves very little opportunity to develop serious consciousness towards DEI attributes outside of the required courses of a 120 credit program.

The IL framework offers useful insight on how to integrate models for learning and habits of mind that can ensure soft skill development. The limitation in the range of the soft skills in the GTCM can be overcome by including student disposition and instructor positionality (e.g. [27]) in a framework for geospatial literacy. Casting DEI into the geospatial literacy imposes the intersection of UDL principles, models for learning, and STEM-critical pedagogy. We anticipate that this framework can offer significant enhancements to STEM-critical pedagogy and the learning of the GTCM to empower student’s critical thinking on pervasive inequalities within the built environment.

3.1. Instructional Design

The concept of universal design emerged from the field of architecture where buildings were universally designed (e.g. providing ramps, elevators, or automatic doors) to accommodate people with disabilities [28, 29]. The concept of universal design was applied to learning to facilitate flexibility in curricula and to offer improved access to information and to learning. Thus, UDL is not a one-size-fits-all approach but rather a blueprint for designing educational goals that facilitate multiple avenues to access, execute, and engage curriculum content for all learners including those with diverse needs [28]. Three main UDL principles are based on three primary brain networks (e.g. [29, 30]), namely: 1) the recognition network that supports access to comprehend information, concept and ideas - the "what" of learning, 2) the strategic network that supports action or expression of their learned knowledge - the "how" of learning, and 3) the affective network of the brain that facilitates engagement - the "why" of learning (e.g. [29, 31]).

Instructional design for engineering education, by definition, is the process by which learning materials and experiences are designed, developed, and delivered [32]. Learning materials include instructional manuals, video tutorials, learning simulations, etc. Learning experiences result in the acquisition and application of knowledge and skills which is facilitated by instructional design. Good instructional design helps learners manage their cognitive load by ensuring a balance between their working memory and inputs from multiple sensory channels, such as listening to instruction, while at the same time interpret language, visually examine graphs, equations, and imagery with follow-through on task completion (e.g. [28, 29 and references therein]). Instructional designers are the 'architects' of the learning experience. The delivery of an instructional instance, whether face-to-face learning, online learning, or any hybridization of the two, requires intentional and organized instructional design [33].

There are many instructional design models but they all share a common base of design elements where the educator/designer must a) define the problem or knowledge gap that the instruction is meant to address, b) identify the audience that the instruction is meant to serve, c) develop learning objectives and assessment strategies, d) select and sequence the content and associated learning activities, and e) build a cycle of revision.

3.2. STEM Pedagogy

Pedagogy, in general, is defined as instructional techniques and strategies which enable learning to take place. It involves the method and practice of teaching with a particular focus to elicit intellectual curiosity by valuing the affective side of learning. It refers to the interactive process between teacher/practitioner and learner and includes the physical environment where the learning takes place and the actions of the family and community (e.g. [34]). The primary concerns of critical pedagogy may be described as ways of thinking about, negotiating, the production of knowledge, and including the social and material relationships of the wider community (e.g. [33 and references therein]).

STEM agendas have well-developed curricula that concentrate on 21st century skills including inquiry processes, problem-solving, critical thinking, creativity, and innovation as well as a strong focus on disciplinary knowledge [35]. Pedagogical practices through a project-based approach requires that students apply content knowledge to solve problems through integrating multiple subjects of Science, Technology, Engineering, and Mathematics. Students learn by doing. Therefore, educators should understand the value and power of the process that enables students to fail and persevere. Teachers are the single most important factor as they are STEM practitioners who provide learning that encourage critical thinking and innovation while building understanding of content and concepts [36]. The teacher's role as a catalyst is to guide students to examine problems from all angles through questioning.

STEM pedagogy, on the other hand, involves a large community of practice made up of smaller separate communities of practice of the STEM enterprise. Each disciplinary domain or community of practice like Science, Technology, Engineering, and Mathematics is different and has its own unique and distinctive knowledge practices that cannot be changed. Learning in a specific community of practice involves making sense in a social context of the particular community of practice [35]. Student members of the smaller communities have multiple memberships. Margot and Kettler [36] explains that teachers and the STEM curriculum play the roles of catalysts in the talent development process. While the curriculum is simply a blueprint, teachers not only design a problem-solving lesson sequence for students to follow [35], they also negotiate dynamic barriers and challenges to develop STEM skills in the classroom. STEM pedagogy encompasses principles that allow students to work as professionals within the disciplines of Science, Technology, Engineering, and Mathematics, while solving real-world problems in which they are interested [36]. However, within this ecosystem, a major task for teachers is to develop a dynamic pedagogy on how to negotiate the interaction with and mobilize translation to cross the boundaries between the different STEM domains [35]. In this regard, the teacher will facilitate and organize by invoking dialogical processes (i.e., identification, coordination, reflection and transformation) and pedagogical activities (i.e., asking students to solve a relevant authentic ill-defined problem in multiple creative ways) to facilitate boundary crossing between the STEM domains. Taken together, STEM pedagogy is posited as boundary crossings within the STEM enterprise [35].

STEM-critical pedagogy involves designing dialogical processes and pedagogical activities that align with the affective elements, particularly curiosity, and can serve as a necessary catalyst for the cognitive element of learning that facilitates boundary crossing between the STEM domains to solve ill-defined problem in multiple creative ways. Such perspective has potential to transform society and achieve social justice through education.

3.3. Models for Learning

A variety of theories of learning, from behaviorism through constructivism and others, have been investigated relative to STEM programs [37]. While behaviorism theory promotes learning through practice, repetition and feedback to reinforce memory associations, it does not engage with how the mind influences learning. Constructivism, on the other hand, captures the value of teachers in a similar vein as STEM pedagogy, while connectivism posits that learning follows from activating the learner's participation via internet technologies [37]. An in-depth discussion on their respective advantages and disadvantages is beyond the scope of this article, but it is worth noting that these learning theories are silent on the disposition attribute within the education ecosystem. Therefore, we chose to follow the IL framework and select the growth mindset, design thinking, and the disposition attribute (of both instructor and learner) as an integral part of the GTCM framework. Each of these models for learning have important aspects that facilitate and explicitly incorporate soft skill development such as DEI outcomes for professional degree programs.

3.3.1. Mindset

Mindsets or habits of mind play a pivotal role in human development. The extent to which students view their intelligence improvable influences their thoughts, behaviors, and ultimately their academic success. A growth mindset believes improvement is possible that their talents and abilities can be developed by investing effort, and academic success can be achieved through good teaching and persistence (e.g. [36, 37]). On the other hand, a fixed mindset is linked to behaviors that seek to avoid challenges and reduced learning which reinforce beliefs that personal skills, traits, and talents are fixed [37]. Such a fixed mindset clothes its owners with incompetence and they attribute their failures to external uncontrollable factors [38]. However, quantitative studies suggest that students' mindsets continue to develop and change during their first year of college and that successful mindset interventions have boosted students' grades and persistence in STEM [38]. Developing a growth mindset amongst students is not an immediate process; rather, it will take a concerted effort on behalf of teachers and the rest of the schooling community (e.g. [37, 39]). Moreover, an educator's own positionality can influence learning trajectories of their students [33, 40].

The instructional *positioning* of the instructor plays an important role in advancing learners' abilities within the geospatial information/skill education ecosystem. In short, a particular mindset (i.e., fixed versus growing) can inform how an educator can either stymie a student's development or help it to emerge and develop further. A growth-mindset teaching pedagogy can help students develop a growth-mindset belief system about their own abilities [40]. Accordingly, educators must recognize their past teaching practices and possibly reframe those practices to be more inclusive (adaptable to diversity in learner attributes, backgrounds, and beliefs).

3.3.2. Design Thinking

Design is generally thought of as formal and expert activities reserved for a few professionals such as architects, designers, and professional engineers (e.g. [41]) whose design, through specialized training and years of practices, often lead to valuable end-products. But design can simply mean a person's approach to identify and solve a problem. Humans perform informal and formal designs in daily lives such as in travel planning, house decorations, backyard landscaping, gardening, and school projects. Such activities involve cognitive processes of problem solving and decision making which, in turn, borrows from elements of design [42].

Thinking has been posited as plural, meaning that it can be differentiated as multiple models with levels (in STEM), instead of a single individual-based cognitive process [41]. In this context, thinking is dichotomized as having lower and higher level cognitive actions. Lower level cognitive actions, which reside at the physical and perceptual levels, involve abstraction of the problem statement through actions. Such actions include drawing or sketching, looking, and recognizing graphical features and spatial relations. Higher level cognitive actions, that reside at the functional and conceptual levels, command goalsetting and decision making. Therefore, design thinking occurs in many STEM and non-STEM fields [41, 43].

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. The 5-stage cognitive processes in DT are discovery, interpretation, ideation, experimentation with feedback, and evolution (redesign or refinements). Therefore, an imperative when designing or revising a curriculum is to design components that consider the student as a naive and curious outsider [41, 43].

Developing DT requires deliberate specification on the 5-stage process throughout the learning experience. During the *discovery* step, the curriculum designer invokes design research 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, understands how end-users respond to the idea, and then follows up to optimally align with their needs and facilitate 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 educational designers pause to 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-users' perspectives [40]. DT complements traditional curriculum design approaches by emphasizing qualitative methods and techniques for creating information from raw data.

3.3.3. Disposition

Merriam-Webster dictionary defines disposition as the usual attitude of a person or a tendency to act or think in a particular way. More specifically, a disposition can be explained as the temperamental makeup of an individual armed with a set of capabilities that allow the individual's preferences, attitudes and intentions to become realized in a particular way. Disposition is integral to the IL education framework which was developed by the Association of College & Research Libraries (ACRL). A unique aspect of the ACRL framework is the threshold concept (TC) which represents a portal in an ecosystem for conceptual understandings and actions (e.g. [27]). Portals are passageways to enlarged understanding or ways of thinking and practicing within a particular discipline. A TC (portal) hosts, among other things, two important elements for learning goals, namely expert-level knowledge practices and disposition or attitude. Knowledge practices are what a domain expert exhibits during problem solving. Disposition is the mental attitude of the learner that affects the learning. Movement through and beyond a threshold is a transformational process for the learner. Disposition either denies or consents passage through a portal.

Disposition should be intentionally integrated into GTCM to benefit both the learner and the instructor. Instructors can nurture the affective attribute in learners and by the same token allow themselves opportunity to develop an awareness of the importance of assessing content with a skeptical stance. Teachers hold a pivotal role in a student's skill (or talent) development, and therefore, their prior views and experiences can significantly influence their STEM instruction and the learning outcomes for students. An imperative for STEM educators is to challenge their own disposition through introspection and to keep a restraint on their own bias.

The GTCM framework will intentionally include UDL principles, STEM-critical pedagogy and models for learning with a balance on hard and soft skills as student outcomes that meet industry needs. The framework thus establishes an alternate guide for curriculum development that heightens intellectual curiosity with relevant professional acumen and soft skills to empower students to tackle difficult technical problems in engineering and social sciences that carry remnants of colonialism-induced social injustices.

4. The Conceptual GTCM Framework

Figure 2 depicts the generalized framework for learning and teaching the GTCM with a particular set of outcomes. The generalized framework recommends a recursive and iterative process with feedback to assess outcome attainments and afford opportunity to revise and improve in order to reach the desired student outcomes. This framework integrates various elements from UDL, STEM-critical pedagogy, and models for learning. This framework offers a holistic curriculum guide for GTCM-based education programs of the geospatial industry. Successful learning of both hard and soft skills is predicated on pedagogical strategies and effective instructional design approaches aimed to leverage the intellectual curiosity, growth mindset and design thinking in order to inspire academic success. The framework offers a holistic guide for program design from the novice or undergraduate through to the professional of graduate level.

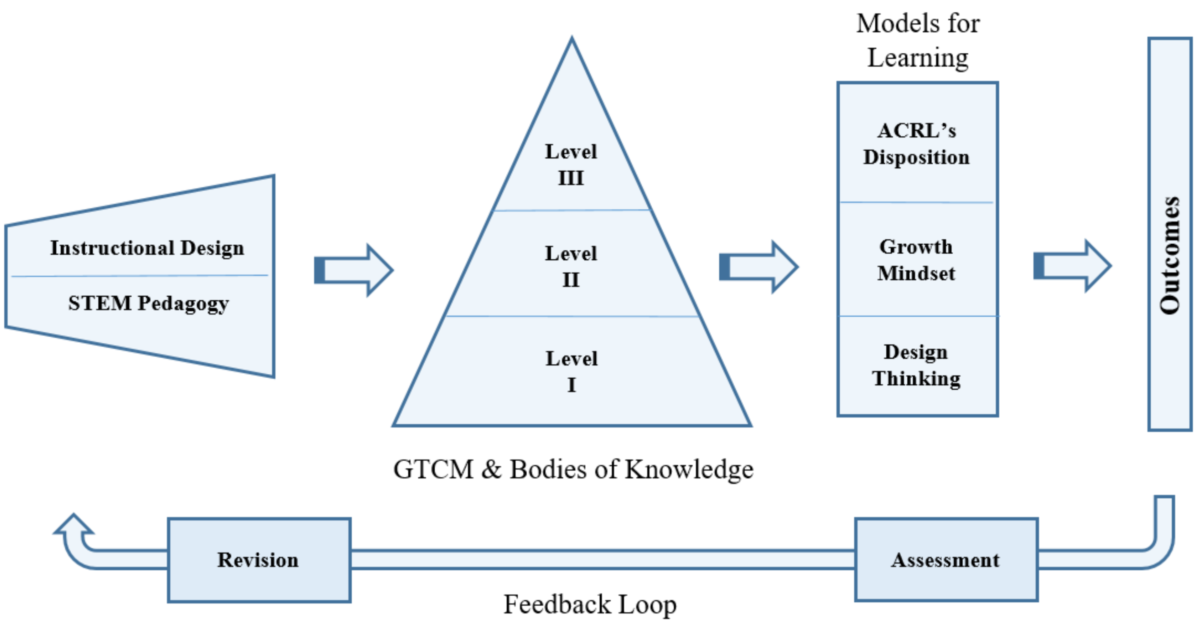

Figure 2: Generalized GTCM framework for learning and teaching with DEI-informed outcomes.

The intersection of instructional design and STEM-critical pedagogy shapes how the subject material will be delivered. Instructional design for face-to-face learning of lower level GTCM content is more suitable to novices while at the same time tries to implement the growth mindset, design thinking and opportunity in order to contrast their own disposition of the subject matter against that of their peers. A face-to face instructional instance offers immediate response/feedback on the disposition of both the instructor and the learner. Classroom setting also affords DT opportunities where students learn in a collaborative setting. Higher level GTCM content instruction may be better suited for self-paced learning in an online environment – with discussion boards. Choosing the right teaching pedagogy is the first step a teacher can take to ensure that students retain course content.

The GTCM competencies are disseminated with the enhanced pedagogy and instructional design tools tailored for specific learner audiences located at Level 1 through Level 3. The learner's experience is tempered by the integration of various models for learning. Curiosity in novice learners must be heightened by the instructional instance and a growth mindset can be perpetuated by the instructors' positionality that facilitates design thinking processes to frame the learning experience.

Student outcomes generally include a list of competencies that are predicated on the curriculum expectation and goals. Balanced student outcomes of both hard and soft skills are predicated on the effective implementation of instructional design, pedagogy, and models for learning. Revisions to instructional designs and critical pedagogy are informed by qualitative and quantitative assessment of measurable student outcomes. Integrating the various models for learning such as disposition, growth mindset and design thinking, this framework offers a significant advancement to the traditional GTCM. This framework shifts the learner from purely a skill literate to an active and critical participate working to develop their abilities relative to curriculum content. The learner's relationship to the learning process is shifted to include knowledge practices and the affective attribute ranging from curiosity and motivation, to confidence in questioning traditional notions and persistence in the face of difficult challenges.

The framework offers a holistic guide for curriculum design and for instructional instances of the GTCM for the various specializations of the geospatial industry from the novice or undergraduate level through to the professional or graduate level. In this framework, the learner's experience is tempered by the integration of various models for learning. This framework explicitly integrates a balanced development of both hard and soft skills along the continuum of a GTCM-based education program. Furthermore, the GCTM literacy framework with DEI-informed outcomes is well-positioned to empower graduates of geospatial engineering and technology programs to recognize difficult problems encountered in professional practice and to approach problem-solving in a new way with DEI tools.

The framework was applied to a capstone course on land development at a 4-yr university. The course includes several phases starting with engineering feasibility, subdivision design, and legal aspects of land development and guest lecture presentations on industry examples, and culminating in a final project with deliverables. For the first phase of the project, students were tasked to perform an engineering feasibility analysis for a 30-acre land development proposal located in a suburban area. This phase was prefaced by a lecture on the application of DEI principles in land and urban development. The feasibility analysis and site development tasks require that students demonstrate understanding of the constraints of municipal land use codes, re/zoning, lot size, types of development, water runoff controls and other environmental factors including the human factor of site development. Students consulted various websites such as the population census, labor statistics, environmental and agricultural resources to inform a site development proposal that speaks to DEI principles. During their brainstorming sessions of phase one (which involved several iterations on different designs ranging from single family, mixed residential, industrial, or mixed use, etc.), the students considered the impact of the interplay of various demographic and socio-economic groups on their proposed designs. Later in the semester a town engineer, as a guest speaker, addressed the class on planning board activities and subdivision permits. When an example of a complex subdivision was presented, the class recognized, challenged, and asked many questions on how such a recent land development project which violates DEI principles was approved. The response included explanations on how town boards navigate public outrage in a give-and-take agreement to satisfy municipal codes and township needs for future development. This example illustrates the effectiveness of the framework not just in creating an awareness of DEI but the potential to imbue students with a willingness to champion DEI principle in their careers.

5. Discussion

Traditional STEM education models are now considered to be incompatible with modern societal issues and values perhaps due to the past three industrial revolutions that focused on technical skills to serve emerging industries and socio-political agendas of the past. Specifically, the first industrial revolution (1IR) circa 1785-1820 transformed the working class (e.g. [44]), the 2nd industrial revolution (c. 1860-1914) brought modern social and economic revolutions via transportation and communication innovations (e.g. [45]), and the 3rd industrial revolution (3IR) ushered the information age and the internet (e.g. [46]). Throughout the three industrial revolutions HEIs devised curricula to prepare efficient, autonomous and technically competent engineers, scientists and technologies to advance society technologically and improve the quality of life. Despite these advances society became fragmented into disparate groups holding vastly different values while other groups became marginalized along socio-economic and social-ecological lines.

Nowadays, HEIs face increasing calls from industry, accreditation services, and others to rethink how to effectively engage with complex 21st century challenges that impact the well-being of our interconnected planet. Society is collectively grappling with threats to democratic governance while enduring injustices and civil discord amidst life-changing disruptions from the global pandemic. Geospatial technologies of the 4IR have emerged to unveil “the good, the bad, and the ugly” of land reuse/cover, land conversions and social-ecological conditions that require urgent attention for social justice. “The good” is that geospatial technologies are key tools for a host of location-based information including environmental mapping and analysis, tracking urban safety, revealing land re-use/cover practice and provide feedback to policy makers for social justice across many domains. For example, RS and GIS technologies proved invaluable on pandemic recovery efforts (e.g. [47, 48]). Space-based sensing tracks the location of socially vulnerable communities exposed to the threat of climate change (e.g. [9]) and can inform effective reallocation policies.

“The bad” practices of the past are revealed through RS imagery and GIS analytics which document unsafe and hazardous conditions in neighborhoods [10]. The effects of climate changes appear to be more pronounced in locations where low-income and racial minorities live [9] and negative environmental stressors are highly correlated with inner city neighborhoods [11].

“The ugly” problems revealed are that land reform programs in post-colonial countries still retain previously unknown gender inequalities in land rights as well as poor land tenure fundamentals [12]. In the US, aggressive land conversion of agricultural land for residential and commercial use mobilizes urban sprawl. At the fringes cross-migration wreaks havoc on the fragile societal fabric where moral, religious, and traditional American values collide. As a consequence, spatial and social boundary changes highlight institutional and commercial interest that often exacerbate spatial inequalities and localized access to natural resource and essential public services [10].

Geospatial scientist and professionals (i.e., geomatics engineers, surveyors, civil engineers, urban planner, GIS professionals etc.) serve important roles in resource mapping, boundary discovery, urban planning, land development and often act as facilitators and mediators in rationalizing land conversion projects, the use of urban space, the deployment of municipal and community resources, and the allocation of community and economic development opportunities [3]. Geospatial technology offers key tools to understand the underpinnings of social injustices and in turn, recommend via their respective professional societies (e.g., NSPS, ASCE, NAE) urban ecological planning initiatives so that policy makers have clear understanding of the social-ecological and political benefits of implementing responsible land use practice, green and blue infrastructure, and their interactions (e.g. [49 and references therein]). The accomplishments of the past three IRs in the built environment may be admired and viewed as “that’s how it was” during colonial times. Now, there is an expectation that graduates of academic programs will be equipped in their training to engage and manage equity matters within the context of their professional practice. Therefore, it is critical that instructional instances help students develop a concern for social justice before they enter professional life. Educational programs borne from the GTCM are well positioned to respond to the call for HEIs to deliver changemaking education. 4IR technologies coupled with DEI-informed STEM education can mobilize future geospatial professionals to enact DEI-principles and values that affirm equal social justice for all.

Through this framework, the learner’s experience is tempered by the integration of various models for learning. Individuals with a growth mindset focus on process and progress, searching out opportunities to stretch their existing abilities. Curiosity in novice learners must be heightened by the instructional instance and a growth mindset can be perpetuated by the instructors’ positionality that facilitates design thinking processes to frame the learning experience. With a growth mindset, educators must recognize their past teaching practices and possibly reframe those practices to be more inclusive of the variety of social problems in the geospatial context of land use/cover. For example, an assigned problem statement can be designed that requires students to use geospatial data to invoke the “How Can I” or “How May

We" scenario in order to work toward a solution. The problem must require students to produce sketches of the spatial arrangements of the various elements in the problem statement in order to invoke principles of DT. A RS problem statement could require students to investigate and highlight previously overlooked social problems induced by land development practices, exploring and dissecting directives on socially responsible land use/cover and inundation disaster recovery, or identify socioeconomic factors that negatively impact the safety and welfare of various communities. Such work necessitates enacting the incremental theory of intelligence, incorporating a deeper understanding of the end-users, exploring their perspectives, and to do right by our learners [33, 43].

The framework as constructed establishes an alternate guide for curriculum development that heightens intellectual curiosity with the relevant professional acumen and soft skills to tackle difficult problems in geoscience that bares remnants of colonialism-induced social injustices. While teachers hold a pivotal role in a student's skill development, their prior views and experiences can significantly influence their STEM instruction and the learning outcomes for students. The framework requires educators to challenge their own disposition through introspection as they prepare students to tackle difficult societal problems over the course of their professional careers. However, it is anticipated that the progressive values espoused by this paper will encounter difficulty in finding resonance and opportunity to flourish in practice and advance equity outcomes. We aim to highlight how a geospatial educational framework can empower next generation professionals to examine, address, and explore systemic and institutional perspectives and practices that enable or disable existing social justice gaps present in society.

6. Conclusion

Higher education institutions face increasing calls to rethink how they can better engage with complex 21st century challenges that impact the well-being of our interconnected planet. This paper offers a response to this call by presenting a framework for teaching and learning GTCM technical skill in concert with DEI-inform outcomes. It is anticipated that the implementation of this new framework will empower instructors and students to be open to explore systemic biases, perspectives and practices that enable social injustice within the built environment and at the same time challenge and address systems of inequity in land use. 4IR geospatial technologies like GPS, GIS and RS offer unprecedented opportunities to investigate solutions to social injustices and vulnerabilities within the built environment. Geospatial professionals and practitioner, through their professional societies, can participate on identifying social injustice, divisive policies from the past practices and policies that galvanize exclusion, homogeneity and perpetuate vulnerabilities of marginalized communities.

We have constructed a conceptual and flexible framework of geospatial literacy training in response to calls for reskilling the geospatial workforce for the 4IR. This framework overcomes the limitation of the DOLETA-inspired GTCM which focuses primarily on technical skill developments without explicit attention to soft skills. By intentional integration of STEM-critical pedagogy and UDL principles, in tandem with models of learning such as disposition, growth mindset, and design thinking, instructional designs can be strengthened primarily by engaging soft skills along the continuum of GTCM technical skills. The framework coerces instructors to examine how their own mindset and positionality affects teaching and explore elements of design thinking to empathize with and ideally dismantle barriers to learning. This approach should find support from professional societies, accreditation organizations, and the society at large. In contrast to the traditional GTCM, our proposed framework portrays the relationship of students to geospatial engineering/technology/information and skills as active participants concurrently learning and working to develop hard and soft skills, specifically DEI abilities. By incorporating the models of learning, UDL principles, and STEM-critical pedagogy, this framework will elevate STEM-critical pedagogy and instructional design to deliver instructional instances in geospatial literacy that challenge student notions of social injustice within the built environment and, at the same time, empower them as Changemakers in their professional practices by espousing values of diversity, equity and inclusion.

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