CURRENT ACADEMIC STUDIES IN TECHNOLOGY AND EDUCATION 2023

EDITORS
Dr. Christopher Dignam
Dr. Mustafa Tevfik Hebebci

ISRES Publishing

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Review Process

Any paper submitted for the book chapter is reviewed by at least two international reviewers with expertise in the relevant subject area. Based on the reviewers' comments, papers are accepted, rejected, or accepted with revision. If the comments are not addressed well in the improved paper, then the paper is sent back to the authors to make further revisions. The accepted papers are formatted by the conference for publication in the proceedings.

About the Book

The intersection of technology and education exerts a profound and far-reaching influence on societies and learning environments across the world. *Current Academic Studies in Technology and Education 2023* is the latest in a series of texts published annually from selected papers invited by the editors. The present edition consists of contributing international authors from Georgia, Türkiye, the United States of America, and Uzbekistan. All submissions are reviewed by at least two international reviewers.

The present publication of *Current Academic Studies in Technology and Education 2023* consists of ten chapters, with each chapter focused on a diverse, yet unified, selection of technology and education. The purpose of the book is to provide readers with the opportunity to examine scholarly, peer-reviewed publications in the field of educational technologies. Every chapter affords valuable insights and knowledge, shedding light on the global significance of the intersection between technology and education.

Citation

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Foreword

Current Academic Studies in Technology and Education 2023 provides insight and perspective concerning the interdisciplinary and transdisciplinary intersections of educational technologies and their collective relevance for learning. Each invited author possesses a variety of relevant experiences and achievements concerning technological innovations – and educational inspirations – for improving learning. While each invited author enjoys a unique background and practice, every author collectively presents an invaluable compendium of meaningful, relevant viewpoints concerning the utilization of technology and education.

The present edition, and the chapters contained within, provides perspective regarding a range of topics, including STEM and STEAM philosophical and technological design, artificial intelligence, digital transformation, technology integration, nanotechnology, virtual laboratories, digital media, and teaching culturally and linguistically diverse students. While the topics within each chapter are both unique and interrelated, the overarching theme is improving the quality of education. Moreover, and perhaps most importantly, each chapter independently and collectively asserts possibilities for the future, as we share a global society and the intersection of technology and education impacts societies more than ever.

As the editors of *Current Academic Studies in Technology and Education 2023*, it is our hope that the theoretical-empirical nature of these works illuminates not only the past and present states of technological education, but ultimately, the possibilities the future presents.

December 2023

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Table of Contents

Utilizing Digital Autoethnography for STEAM Education and Leadership Nurturing

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To Cite This Chapter

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Introduction

Employing a variety of visually stimulating interactive strategies through a digital platform is a contemporary approach for eliciting reader and learner interests. The utilization of educational technologies provides opportunities to immerse educators with authentic Science, Technology, Engineering, Art, and Mathematics (STEAM) exemplars and educational leadership artifacts for motivating interests in leading programmatic development. In an effort to provide a forum to present STEAM curricular materials, contemporary STEAM research and laboratory design artifacts, and educational leadership exemplars, the researcher employed autoethnography methodology and developed a digital, online environment for nurturing leadership (portraitureeducation.com). The researcher assembled authentic career exemplars over the course of a 27-year span to illustrate STEAM and educational leadership in an interactive, digital environment for pervasive learning. The researcher employs the digital environment for students to utilize in higher education courses and during internships while earning educational licensure. The digital environment was based on the researcher's ten years of experience as a high school science teacher (biology, chemistry, and physics) followed by seventeen years as an administrator, principal, and community school district superintendent leading the development and implementation of STEAM programmatic offerings and classroom space redesigns.

Digital Graffiti

Autoethnography is grounded in both narrative and ethnographic research methodologies and employs an expressive description of phenomena blended with arts-based investigative approaches (Cooper & Lilyea, 2022). Autoethnography is a wonderful research methodology that provides a researcher with opportunities to connect personal experiences for understanding (Ngunjiri et al., 2010). This particular methodology also allows creativity in providing descriptors related to phenomena, which is in line with the researcher's personal and professional interests in designing creative, innovative STEAM programmatic offerings. Given the researcher's past decades of experiences as both a science educator, principal, and superintendent leading STEAM programmatic development and implementation, the researcher utilized autoethnography as a methodological approach for narrating and immersing the self in descriptions to create an embodied experience for the reader (Chang, 2016; Ngunjiri et al., 2010). The exemplars explored in this chapter are presented as textured, lived experiences to evoke imaginative understandings and self-interests of each reader regarding a variety of interdisciplinary STEAM programs that were developed, why they were developed, and how they were implemented. Each section of the chapter concludes with "Perspective-Taking and Considerations" regarding the digital exemplar and implications for employing the exemplar in nurturing leadership in students in higher education.

Visual Graffiti

A unique aspect of utilizing technology through an arts-based narrative, methodological approach is the digital platform the researcher created is an authentic product of STEAM philosophy in motion. The digital environment is a blending of self-portrayed STEAM programmatic offerings via digital autoethnography. The site serves as a digital storyteller's canvas for providing authentic artifacts that detail curricular instructional design, classroom composition, programmatic implementation, community engagement, connecting with stakeholders, and leading for all. Employing digital autoethnography provides a nontraditional approach for creating an interactive, online environment for leadership nurturing. The chapter is arranged into three sections: (1) Girls in Engineering, Math, and Science (GEMS), (2) Art in Mathematics, and (3) The Chemistry of Art. Each section provides an immersed perspective for the creation of innovative STEAM programs and learning spaces that inspire learners to learn and for teachers and educational leaders to support the lived experiences of students.

Girls in Engineering Math, and Science (GEMS)

Mystical Graffiti

In the United States today, females only represent fifteen percent of the workforce for electronics engineering and twelve percent for computer science (González-Pérez et al., 2020). In addition, only seventeen percent of registered architects are women with just 25 percent of women earning a degree as a physicist, which is the lowest amongst all the physical sciences (American Immigration Council, 2022; González-Pérez et al., 2020). Occupations in Science, Technology, Engineering, and Mathematics (STEM) are projected to grow fifteen percent through 2031 while the number of students in the United States electing to earn an undergraduate STEM-related degree is decreasing (American Immigration Council, 2022; Brooks, 2023). All the while, females remain underrepresented in the STEM workforce with an increasing demand for degrees and employees to fill important, needed roles. Consequently, the United States seeks workers from outside the country to fill much-needed STEM-related positions (especially in areas of engineering). This phenomenon, however, is not new. Since the 1990s the number of foreign-born STEM workers in the United States has increased with one-fifth to one quarter of the STEM workforce being represented by foreign-born employees (American Immigration Council, 2022; Brooks, 2023; González-Pérez et al., 2020).

While these statistics create pause in terms of challenges impacting STEM education and the workforce, they have been increasing over the past two decades. Female underrepresentation in STEM, the increasing demand for STEM-related careers coupled with decreasing undergraduate degree conferral, and the need to look outside the country to employ STEM workers within the United States are phenomena educators and employers continue to address and confront. The researcher partnered and collaborated with dynamic STEM and STEAM educators throughout his career to create solutions for increasing the numbers of disproportionately underrepresented student subgroups in STEM courses. A good portion of this work relied on including teachers, students, parents, and stakeholders and creating an atmosphere of collegiality to identify instructional practices, address mindset, and close school wide gaps for attending to deficiencies (Shahali & Halim, 2023).

Visible Graffiti

Rather than simply telling teachers what was observed school wide and within classrooms, the researcher created opportunities to construct professional dialogue between educators to empower them to identify areas for improvement firsthand. Non-evaluative opportunities for professional discussions via collegial coaching were provided to facilitate these conversations along with our observations (Røkenes, 2022; Shahali & Halim, 2023). Collegial coaching was utilized to provide a construct for colleagues to observe one another and further collaborate by employing a process for guiding professional discussions and self-reflection (Dantonio, 2001). Collegial discussions were utilized as a strategy for engaging STEAM teachers and creating authentic dialogue for leading and coaching. Collegial coaching provides a non-evaluative setting to facilitate interaction, collaboration, and dialogue. The organic nature of the coaching processes is participatory and reciprocal, which facilitates professional discourse (Dantonio & Lynch, 2005; Røkenes, 2022).

In some instances, collegial coaching created difficult, yet fruitful, conversations (Harris & Jones, 2019). These conversations included colleagues observing, for example, that female students in physics were called upon with significantly less frequency than their male counterparts. This was not isolated to just one classroom and warranted professional self-reflection regarding beliefs, values, and professional practice (Shahali & Halim, 2023). In the most difficult, yet courageous conversation, a female teacher developed awareness of her own inherent bias in terms of infrequent interactions with her own female students. The professional practices of the teacher were, of course, surprising to her but created meaningful self-reflection. As a result of the collegial coaching process, she was empowered to reflect on her practice and made a concerted effort to call on and check for understanding with female students to better engage all learners. Creating a forum to discuss instructional practice in a non-confrontational manner ultimately facilitates improved relationships between teachers and students, resulting in leadership development in teachers (Harris & Jones, 2019; Røkenes, 2022; Shahali & Halim, 2023). Coaching and teacher leadership leads to improved curricular delivery, instructional practice, and evaluation of students (Shen et al., 2020).

In addition to creating professional discourse with regard to unintentional bias and professional habits of mind, the need to better encourage and support female students to consider professions in STEM-related fields was also identified. Discourse was important for professional development, as well as observed and self-perceived teaching practices in an effort to collectively own outcomes (Esterhazy et al., 2021; Kaufmann & Ryve, 2019). A school wide concerted effort, structure, and process was needed to reach students throughout the school and not just within STEM-related departments. As a result, the researcher established a Girls in Engineering, Math, and Science (GEMS) program to address the gender gap in STEM-related fields. GEMS was founded to build capacity in young women entering the fields of math, science, and engineering. A large portion of efforts centered on educating girls on how to be successful in these fields by accessing female experts through field trips, guest-speakers, research with universities and organizational partners, and through service learning efforts. What began with just a dozen female students grew to 70 and then doubled in size to 140 student participants in the period of one year. Within another two years, the program had over 300 female students participating.

Perspective-Taking and Considerations

Effective school leaders are able to guide the learning organization through continuous change and improvement for all learners (Kiral, 2020; Shields & Hesbol 2020). The inclusion of the development of the GEMS program affords digital site visitors opportunities to reflect on practice as a result of viewing additional authentic artifacts. Oftentimes, change is not simply developing innovative, creative programmatic offerings, but rather, deconstructing practices and habits of mind to construct new STEAM teaching and learning opportunities via digital leadership (Sheninger, 2019). Throughout this continuous process, school leaders will encounter change and the indistinguishable counterforce of resistance (Sasson et al., 2022). An analogy can be made between change and resistance and Newton's Third Law, which states that for every action there is an equal reaction. Similar to this principle, change and resistance are intertwined forces commonplace within learning organizations (Hubbart, 2023). The degrees and intensity of change and resistance may fluctuate, but they are constants that all teachers and school leaders must be capable of embracing to ensure the continuous success of the learning organization (Sasson et al., 2022; Shields & Hesbol 2020). This particular autoethnographic narrative provides deep discussions with prospective students in higher education related to considering the backgrounds of all students and that all learners are provided access to curricular and extracurricular offerings.

In Arte Mathematica

Integral Graffiti

Over the course of many years as an educational leader, the researcher experienced a great deal of success in affording students with creative ways to approach mathematics. Oftentimes, students are intimidated in terms of enrolling in mathematics courses at the high school level and only choose to enroll in mathematics electives if they are required to do so or only if they are genuinely interested in mathematics. In addition, freshman and sophomore off-track data tends to reflect students struggling the greatest in terms of high school mathematics coursework at the ninth and tenth grade levels as opposed to the other content areas (Schmidt, 2012; Son & Stigler, 2023). These challenges are compounded further when students who fail or earn a “D” (an academic “F”) in freshman algebra are nonetheless automatically enrolled into the next semester or even the next year’s sophomore-level geometry or algebra II course. Educators must consider if we are unintentionally creating a conveyor belt, systemic milieu that contributes to an inherent dislike for mathematics in high school students (Springer et al., 2007). Furthermore, this structural setting reinforces negative student perceptions regarding mathematics and contributes to off-track student predictors at the onset of high school, impacting the likelihood of high school graduation (Schmidt, 2012). As a result, there are very few mathematics electives students will choose to enroll in unless they are forced to do so or are intrinsically motivated to learn mathematics. However, developing creative programs that employ active, participatory learning reduces poor mathematics performance for students of all backgrounds and prepares learners as they transition to higher education STEM coursework (Theobald et al., 2020).

Quizzical Graffiti

A course the researcher has offered students as a mathematics STEAM elective is Art in Mathematics. The researcher has afforded students the opportunity to enroll in Art in Mathematics in a variety of high school environments, ranging from a selective enrollment college preparatory high school setting to a therapeutic day school learning environment for special needs students. The researcher has observed students flourish across a spectrum of rigorous settings and thrive as a result of taking this particular course. As a result, students exit the course with a greater love and appreciation for the world of mathematics surrounding each of us daily. Providing all students with access to meaningful, hands-on STEM experiential learning acts as a catalyst in motivating students to further engage in STEM learning (Kolb, 2014; Maiorca, 2021).

Employing a creative, innovative approach towards learning mathematics via interdisciplinary teaching and learning results in a deeper appreciation for the subject matter and affords opportunities for teachers to engage in cross-curricular instruction. Interdisciplinary and cross-curricular learning positively impact student achievement in both mathematics and science learning and connect domains of STEM offerings (Cotic, 2021; Serpe, 2022). The following is an overview of digital autoethnographic content for readers and higher education students that not only includes STEAM-related curricula in Art in Mathematics, but also incorporates social constructs and cultural units of study within this interdisciplinary framework. The inclusion of socio-cultural contexts is valuable for providing perspective regarding the social, emotional needs of all learners and students and for ensuring social constructs are in place to support student motivation, needs, and cognitive choices for all learners (Eccles & Wigfield, 2020).

Golden Ratio

Students are introduced to Art in Mathematics curricula by developing an understanding of the golden ratio in art and architecture as well as the occurrence of the golden ratio in nature. These approaches include learning patterns in Fibonacci numbers (sequence) and related artwork students observe and create to reflect understanding. The concepts of patterns, proportions, and symmetry are introduced with respect to how they occur in nature and in artistic and architectural design (Figure 1). Students create mathematical sequences for art via Euclid's study of the golden ratio and its appearance in some patterns in nature (for example the spiral arrangement of leaves and/or plant organs and structures).

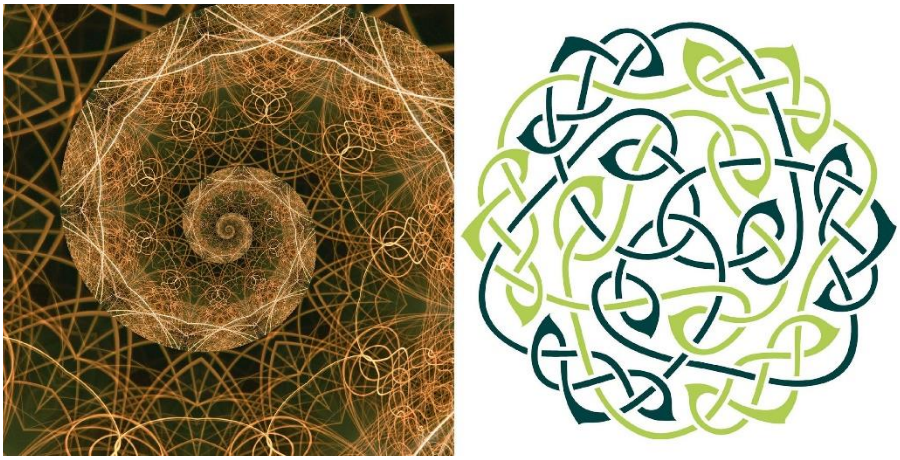

Figure 1. Fibonacci sequence and celtic knot

Proportions and Perspective

Students are provided a mathematics and artistic review of proportions in the human body and the history of anatomical research throughout time. Students learn about the Renaissance and human proportions reflected in art, proportions in architecture (in both a historical and cultural context), and proportions of the Egyptian pyramids for an introduction to geometric learning (Figure 2). Students explore the historical use of perspective in paintings and the diverse (and complex) employment of perspective during the Renaissance and Chinese art.

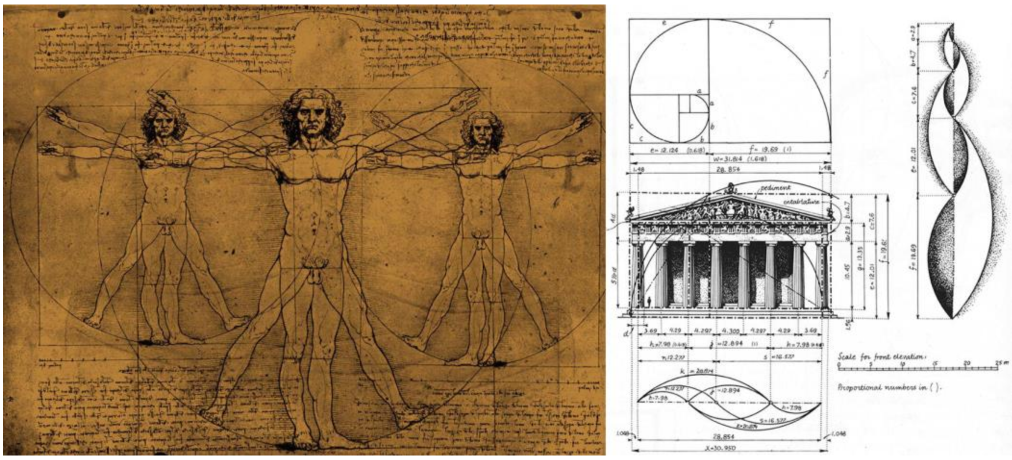

Figure 2. Proportions of the human body and architecture

Symmetry and Patterns

Introduction to mathematical and artistic constructs of symmetry (beginning with demos on the complex beauty and nature of soap bubbles) consist of patterns with an inclusion of the cultural, artistic and mathematical constructs of Asian, Islamic, and Celtic art. Concepts include symmetrical patterns in Asian art, patterns in Islamic art and architecture, and ornamental symmetry in Singaporean architecture. Students learn the seventeen wallpaper patterns at Alhambra and how knowledge of these seventeen wallpaper patterns may have been learned and employed in Chinese art. Patterns in Celtic knots, textile design, tilings, Penrose tilings (Penrose's two different rhombi shapes and two different quadrilateral kites and darts) and tangrams (seven flat polygons dissection puzzle) are explored. Students manipulate polygons and examine symmetry via five-fold rotational symmetry, reflection symmetry, and translational symmetry. Tessellations (reflection, rotation, translation, glide reflection) in nature and the art and geometry of Origami paper folding in Japanese culture are investigated (Figure 3).

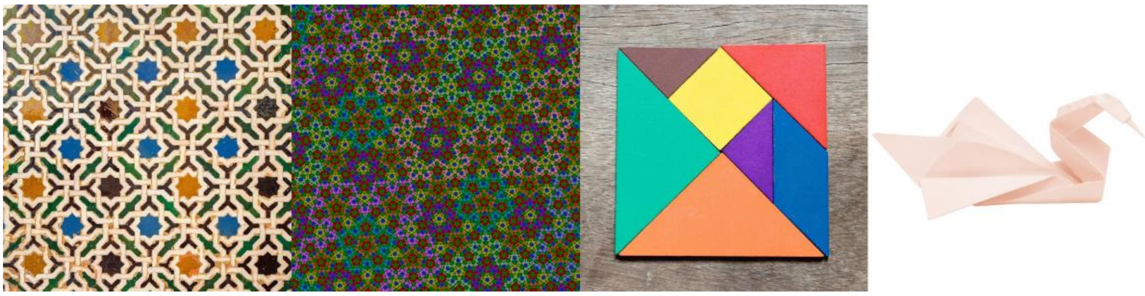

Figure 3. L-R alhambra, penrose, tangram, and origami

Geometry and Architecture

Students explore mazes, labyrinths, and the fourth dimension. These explorations segue into mathematical, artistic optical illusions and the engineering of kaleidoscopes (angles for creating stars). Students are provided an integrated STEAM approach for learning about Polyhedrons (geometry and angles) and stellations in nature and as geometric structures in architecture and design engineering (and a review of Origami). Students discover historical geometric design concepts in fortresses and various cultures utilizing pentagon design constructs, the design engineering of arches (especially in terms of their strength), as well as the geometry of war. Students study the architectural, visual illusions in the Parthenon and the architecture of domes and geodesic domes from both a geometric and cultural perspective. Figure 4 illustrates the geometry of a kaleidoscope, polyhedron, fortress pentagon, and a geodesic dome.

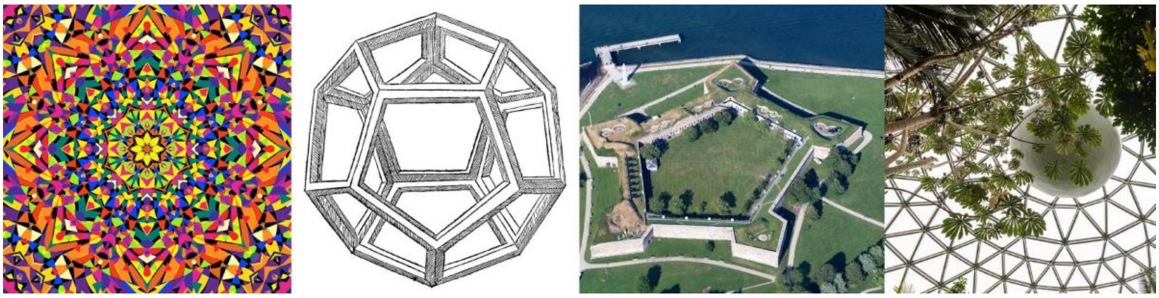

Figure 4. Geometry and architecture

Historical and Cultural Contributions to Mathematics by Artists

The German Renaissance artist Albrecht Dürer’s Melencolia I: Exploration of number appearance and numerology in his work (rows, columns, Dürer’s use of numbers for his second signature, initials, age, etc.). Students learn about historical and cultural beliefs concerning magical/astrological association at the time between magic squares and planets (Saturn and Jupiter 3x3 and 4×4 magic squares).

The mathematically inspired works of the Dutch graphic artist Maurits Cornelis Escher: Exploration of Escher’s woodcuts, lithographs, drawings, and sketches of symmetry and impossible spaces. Review of the geometry of the wall and floor mosaics in the Alhambra and Escher’s fantasy-inspired architectural, perspective illustrations.

German painter Hans Holbein the Younger’s “The Ambassadors’’ painting with anamorphic perspective: Students review mathematics perspectives and view the skull in the bottom center of the composition and render the form via an accurate perspective. Students examine the art of perspective within the portrait and identify items depicted and their cultural, historical relevance (scientific instruments, terrestrial and celestial globes, a shepherd’s dial, a quadrant, a torquetum, a polyhedral sundial, an oriental carpet, and various textiles including the floor mosaic).

Students complete Art in Mathematics coursework through a capstone project on the contributions of the Italian Renaissance artist and engineer, Leonardo da Vinci: Discussions/explorations include da Vinci’s influence on culture, science, technology, engineering, art, and mathematics. Students explore the many facets of STEAM by Leonardo da Vinci and complete a culminating research project on his contributions to modern day culture and living.

Perspective-Taking and Considerations

Mathematics is an incredibly important foundational content area. It does not have to be a course with merely right or wrong answers or designed and perceived as sterile in aim. Mathematics can be an incredibly creative, exciting interdisciplinary course that excites and inspires students to learn more about the world around them through experiential immersion and constructivism (Kolb et al., 1984; Maiorca, 2021). There are a variety of other STEAM-related, cultural and historical interdisciplinary content areas that can be interwoven into Art in Mathematics (fractal art via computer science and mathematics, architecture of the Taj Mahal, parabolic, ellipsoid and spherical geometry of the Sydney Opera House, etc.). Providing a digital autoethnographic environment for delving into the Art of Mathematics provides students in higher education with cultural perspective-taking regarding the social engagements of students in narratives, which is an incredible benefit of interdisciplinary STEAM curricula (Hall et al., 2021; Wolgast & Oyserman, 2020). Embracing creative STEAM design content that incorporates (or at least embraces) discovery learning at all grade levels supports the acquisition of knowledge through constructivist learning (Dewey, 1933; Piaget, J. 1972; Vygotsky, 1978). If the intent of mathematics is to facilitate logical reasoning in students, the impact of mathematical curricular design must be to provide logical reasons for students to be interested in the learning.

The Chemistry of Art or the Art of Chemistry?

Throughout the years, the researcher has provided leadership supports for cross-curricular *art of chemistry* and *chemistry of art* learning opportunities with students in a variety of schools. Some of these learning experiences require just a couple of days of team teaching (and/or swapping classes) while others take on the form of long term, project-based learning that affords students with a much greater depth and breadth of STEAM learning (Diana & Sukma, 2021). These real world *chemistry of art* and *art of chemistry* experiences provide creative, cross-curricular instruction for chemistry learners to make connections to art and for art students to learn the science behind their creations. Cross-curricular instruction is a powerful tool for STEAM, as it facilitates critical thinking in learners that can be utilized for a lifetime of learning (Ross & Gray, 2011).

Raku Glazing

Interdisciplinary ceramics students create beautiful pieces of art all the while learning the beauty of chemistry within their art. Likewise, chemistry students engaged in ceramics-based lessons and raku firing (Figure 5) observe, firsthand, the physical and chemical changes that take place during raku pottery making. In addition, chemistry and art students learned about the historical and cultural origins of traditional Japanese raku firing for creating pottery through a blended, interdisciplinary lens. Raku firing is a method of pottery making that includes students removing pottery from a kiln (while it is still extremely hot) and then placing the pottery into containers for combustion reactions followed by oxygen reduction. There is quite a bit of chemistry occurring during raku firing as well as the process of glazing, which makes this a wonderful project-based learning experience (Diana & Sukma, 2021; Treacy & O'Donoghue, 2014).

During raku firing, students learn about the porous, chemical composition of clay and the physical chemistry that takes place when clay is glazed and heated to temperatures reaching upwards of approximately 980° Celsius. Art and Chemistry lessons include the processes of combustion and reduction. Students engage in the practice of placing clay in a combustible metal chamber with combustible materials (usually paper) where the atmosphere changes and oxygen is reduced out of the chamber. Students observe the science that takes place when combustibles burst into flame and reduce the oxygen as well as crystallization from the thermal shock of metallic glazes (copper, cobalt, etc.) that form metallic colors, such as red, blue, and green.

Students also learn about the minerals of clay (alkali and alkaline earth metals) and the importance of oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium for raku firing. The authentic chemistry and art knowledge students develop provides a valuable opportunity for students to observe the physical changes and transformations of clay during the formation of the pottery they create. In addition, students are able to observe chemistry in motion and learn firsthand about the important, resulting kaolinite structures from raku firing.

Throughout this project-based experience, chemistry and art students are exposed to cross-curricular, co-taught content with respect to the art and chemistry of the ceramics they create. Students also learn about liquid glazes and their composition. Raku firing and glazing of silicon dioxide and aluminum oxide are examined for exploring the physical and chemical properties of silicates that influence the different qualities and atomic structures impacting color, opacity, and texture.

Figure 5. Roku firing

UV Sensitive Fabric Cyanotype

Students in chemistry collaborate with fashion design, printmaking, and art students in studying and exploring UV sensitive materials for cyanotype printmaking. During these chemistry and art experiences, students work with light activated reactions for creating artwork on clothing and fabrics as well as photosensitive paper for display.

Cyanotype is a 170-year-old photographic printing process that uses chemicals to create prints. This process originally became popular due to its ability to easily create duplicated prints (thus the interwoven historical/cultural lessons!). The word cyan comes from Greek, meaning “dark blue substance.” Student works of art reflect a distinct blue (cyan) color. Students in art and chemistry learn about the reaction of ferrous ions to the photo reduction of ferric ammonium citrate in combination with potassium ferricyanide for cyanotype printmaking.

Chemistry and art students are also afforded historical lessons and engineering printmaking background with respect to the process of cyanotype printmaking. Students learn about Sir John Herschel’s work in inventing the process, which was originally intended for reproducing and distributing written records. Students then learn about botanist Anna Atkins’ research in using photosensitive paper (a process is called a photogram) for creating cyanotype prints. Anna Atkins’ work included placing organisms, such as plants, on treated paper. Cyanotype print can also be used with transparent, translucent, or opaque objects to make cyanotype photos. The photos can be made on cloth or paper, thus worn or displayed (Figure 6).

Students duplicate Atkins’ work by placing plants or other transparent, translucent, or opaque objects on photosensitive paper and then placing the items in sunlight for exposure. The results are prints that capture images of the organisms or items placed on the paper that appear as greenish-blue photographic images. This particular experience provides artistic prints that art and chemistry students create. This experience also enables students to examine the physical chemistry of UV sensitive fabrics for cyanotype printmaking. Exploring cyanotype printing serves as a great cross-curricular project between art and science for students to learn about the chemistry of creating sensitizing solutions from ferric ammonium citrate and potassium ferricyanide to create “scientific” works of art.

Figure 6. UV sensitive fabric cyanotype

Tie-Dying and Covalent Bonding

Students can also be provided cross-curricular lessons on the chemical history and artistic use(s) of dyes and how dyes adhere (bond) to fabric. These types of experiences work nicely for interdisciplinary learning between fashion classes and chemistry classes. It also works well with physics (optics) classes when learning about the light spectrum and color absorption and reflection (color absorption and reflection is also covered in biology during photosynthesis). Everyone has owned, seen, or perhaps made a tie-dyed piece of clothing at some point in his or her life, which makes this a fun interdisciplinary STEAM lesson. In addition, learning the science behind tie-dying provides an enjoyable platform for students to create an artistic product they can wear while learning the history and science behind tie-dying.

Students are provided a background on cotton production (biology and economics) and its use for clothing. Students are also provided background on clothing made out of rayon, bamboo, Tencel (wood pulp), hemp, linen and other natural fibers. Students learn about reactive dyes and their propensity to permanently attach to cellulose fibers through covalent bonding. Covalent bonding is a very common type of bonding that occurs when molecules share electrons.

As a side note, whenever the researcher taught chemistry or biochemistry he would have students repeat aloud, “Happiness is a covalent bond!” or “A happy atom is a covalently bonded atom!” for teaching the basics of sharing electrons to complete energy levels for simplistic introductory understanding of chemistry. Tie-dying art lessons provide opportunities for students to develop an authentic understanding of pH, the role of soda ash with dyes, and the role of catalysts in chemical reactions (with respect to the soda ash). Tie-dying and covalent bonding (for a happy atom!) provides opportunities for art and chemistry students to observe the sharing of electrons in motion and create artwork in the form of tie-dyed clothing (Figure 7).

Figure 7. Tie-dye fabric

Chemistry Cubes and Art Computer Design

Art, chemistry, and computer science students engage in cross-curricular lessons using the periodic table, Adobe software, and 3D printers for producing etched cubes (Figure 8) reflecting information from each element on the periodic table. Each side of the cube is produced from a 2” x 2” template (six different templates in all). Students research periodic trends for each element (for example, atomic size, electron affinity, Z-effective, etc.) from the periodic table. Students then make the cubes and build a truly interactive three-dimensional periodic table. Art, chemistry, and computer science students can physically manipulate the cubes to learn/observe trends via a real life, interactive, piece of art. This experiential, cross-curricular project makes learning the periodic table and information about each element much more memorable and relevant to learners of all backgrounds as a result of employing active learning (Cotic et al., 2021; Kolb 2014; Theobald et al., 2020). Students sometimes tend to have difficulty remembering specifics from the periodic table and this project provides an opportunity to build interactive, three-dimensional flashcards using a modern approach for developing problem-solving and critical-thinking skills (Hacioglu & Gulhan, 2021).

Figure 8. Chemistry cube

Perspective-Taking and Considerations

The blending of art and chemistry presents learners with opportunities to view each content area from unexpected lenses. When students engage in project-based learning, they are providing opportunities to employ problem-solving skills and prolonged collaboration. Collaborative interactions provide opportunities to also develop social skills and pro-social relationships (Mahoney et al., 2021; Osher et al., 2018). In addition, cross-curricular lessons afford opportunities for both teachers and students to pool resources, act as a team via discovery learning, and utilize creativity for innovative outcomes. Likewise, employing a technology-based, digital environment with meaningful STEAM teaching and learning narratives, provides students in higher education pursuing degrees in education with an immersive experiential learning space. Prospective, future educators are able to explore real life accounts with autoethnographic narrations regarding what is possible when creatively constructing curricula. The ability to implement creative, team-building curricula promotes relationship building for transferable learning in life (Darling-Hammond et al., 2020). In addition, the utilization of a digital autoethnographic environment provides exemplars of leading education for nurturing leadership in future educators.

Conclusion

The researcher's use of digital autoethnography provides students in higher education seeking careers in education with authentic exemplars regarding the development and implementation of interdisciplinary, cross-curricular STEM and STEAM programmatic offerings. While the exemplars reviewed in the chapter provide valuable insight with respect to the programs reviewed (and implications of immersing prospective educators in autoethnographic narratives) the utilization of technology enables content viewers to delve into layers upon layers of relevant interrelated themes. In addition, the combined power of technology, STEAM, and autoethnography positively impacts and influences a multitude of content areas and educational qualities aside from the acronym of STEAM. These impacts and influences beyond STEAM include sociology, history, geography, culture, language, special needs, social-emotional skills, and perspective-taking.

Principal Graffiti

Creatively employing educational technologies provides an innovative, contemporary approach for presenting authentic educational experiences for teachers, leaders, and education students in higher education. The utilization of digital autoethnography provides authentic perspective for eliciting and nurturing pervasive learning in digital environment site content readers and students. Utilizing a digital autoethnographic methodological technique creates an interactive, ongoing research forum for presenting the shared journeys of STEAM curricular development and meaningful educational experiences of learning communities.

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Empowering Middle School Minds: Harnessing Artificial Intelligence for Innovative Mathematics Education

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Introduction

In the 21st century, artificial intelligence has rapidly permeated various facets of our lives, spanning mobile technology, computing, finance, agriculture, transportation, education, and commerce. Artificial intelligence operates as a personal assistant like Siri and facilitates processes in digital shopping, journalism, stock tracking, medical diagnosis, and potential crime prediction (Castro & New, 2016; Holmes et al., 2019). McCulloch and Pitts (1943) laid the foundation for artificial intelligence's mathematical expression of neural functioning with the Boolean Circuit Model of the Brain. Alan Turing's pivotal question in 1950, "Can machines think?" led to the development of the Turing Test to gauge artificial intelligence's human-like thinking (Turing, 1950, p.1).

Advances in neuroscience prompted researchers to transfer human learning methods to computers and robots, elucidated through comparative studies of the brain and computers, fostering a brain-based learning approach. The primary aim of artificial intelligence studies is to surpass human problem-solving capabilities, with machine learning evolving from rule-based automation to processes overcoming complexity (Dwivedi et al., 2021; Van Vaerenbergh & Pérez-Suay, 2022). Mitchell (1997) characterizes machine learning as the study of algorithms enabling computer programs to develop autonomously through experience.

The artificial intelligence landscape witnessed significant milestones such as IBM's Deep Blue defeating chess champion Garry Kasparov in 1997 and the artificial intelligence program AlphaGo triumphing over Go world champion Ke Jie. Post-2000, deep learning, artificial neural networks, and auditory and visual recognition systems experienced substantial development. Recognition processes' advancements, coupled with cloud computing and big data progress, expedited computational processes and reduced associated costs (Center for Security and Emerging Technology, 2021).

International competition in artificial intelligence, spurred by nations like China setting progress targets, has transformed existing competitive arenas and fuelled economic development (Brattberg et al., 2020; Yu & Lu, 2021). Artificial intelligence, integral to a constellation of emerging technologies, collectively constitutes the "Artificial Intelligence Revolution," impacting robotics, machine learning, cloud computing, genomics, 3D printing, quantum encryption, 5G telecommunications, and beyond (Araya & Marber, 2023; Diamandis & Kotler, 2020). Forecasts suggesting automation of half of global human tasks (Grace et al., 2018; Manyika et al., 2017) and reports of half of organizations already utilizing artificial intelligence technologies underscore the revolutionary nature of this technological wave.

Amidst this revolution, the debate shifts from whether to use artificial intelligence in education to optimizing its efficacy in educational settings. Since the 1980s, researchers have questioned technology's role in education (as explained in Trgalová, 2022). Pea (1985) defines technology's role as empowering and reorganizing mental processes, where empowerment gauges efficiency in traditional tasks, and reorganization assesses alterations in activities and mental functioning (Trgalová, 2022). Consequently, this paper critically reviews the historical context of artifical intelligence, emphasizing the need for a nuanced understanding of its role in education, especially regarding the autonomy of reasoning processes in machines.

The Evolution and Impact of Artificial Intelligence in Education

Since the 1920s, psychologists have aimed to "automate" teaching, with Pressey's work in 1920 cited as an early example of artificial intelligence in education, combining instruction and testing through teacher-guided machines (Pressey, 1950). Presently, the human-machine relationship has evolved, fostering various artificial intelligence applications in education such as personalized learning, verbal communication education systems, exploratory learning support, education data mining, and systems catering to individuals with special educational needs (Arslan, 2017; Papaspyridis & La Greca, 2023).

Research indicates that integrating artificial intelligence into the physical world holds great potential for inquiry-based learning and the development of 21st-century skills like critical thinking and collaboration (Chu et al., 2021; Yannier et al., 2023). Globally, countries have issued policies and reports to deepen artificial intelligence development and application in education, reflecting its significant impact (Luckin et al., 2016; Yu & Lu, 2021).

Anticipating a surge in artificial intelligence investment, especially in developed countries, projections suggest that artificial intelligence education spending will surpass half of the global total, reaching $6 billion by 2025 (HolonIQ, 2019). This investment is expected to enhance productivity for both teachers and students, offering innovative educational services and shaping a new “ecology of education” (Edwards & Magill, 2023; Moate et al., 2021).

Generative artificial intelligence tools like ChatGPT (OpenAI) and Google Bard have demonstrated their impact in education (Aydın & Karararslan, 2023; Grassini, 2023). However, despite these advancements, there is a need for comprehensive research to assess benefits and mitigate potential risks. Educational institutions are increasingly taking on administrative supporting roles, integrating artificial intelligence into learning management systems, school management, campus administration, security, precautions, and finance (Picciano, 2012; Holmes et al., 2019).

Human intelligence has its limitations, and artificial intelligence is poised to surpass these boundaries. Artificial intelligence’s ability to reason over imprecise information, analyze affective situations, and process vast amounts of data quickly positions it as a valuable decision support system, complementing human capacity (DeCanio, 2016; Yu & Lu, 2021).

As businesses and institutions actively design artificial intelligence systems for educational applications, a general framework proposed by Yu and Lu (2021) places “Intelligent Support in Learning Process” at the center, associating it with components like “Intelligent Learning Environment” and “Intelligent Teacher Assistant.” Artificial intelligence serves as an auxiliary tool for teachers, students, school management, and families in various capacities (Knapp et al., 2003; Ouyang et al., 2023).

Three key areas identified by Wang and Cheng (2022) - “Learning from artificial intelligence,” “Learning about artificial intelligence,” and “Learning with artificial intelligence” - offer a comprehensive taxonomy for developing a complementary environment in education. While “Learning from artificial intelligence” emphasizes conceptual theory taught in an environment without teachers, “Learning with artificial intelligence” focuses on using artificial intelligence as a supporting technology in learning processes. “Learning about artificial intelligence” delves into understanding how to use artificial intelligence and its integration into the teaching process, emphasizing the importance of artificial intelligence as a tool to enhance educational practices (Kay, 2015; Tanwar et al., 2022).

Artificial Intelligence and Mathematics Education: From Algorithms to Future Expectations

Algorithms serve as the foundation of artificial intelligence systems, shaping their functionality and classification. Mathematics and mathematics education play a pivotal role in developing artificial intelligence teaching systems, contributing to numerical and programming systems underpinning machine learning, data-driven teaching, deep learning, visual recognition, and reinforcement teaching, and vise versa (Betteridge et al., 2022, Güneş & Saralar-Aras, 2023).

The historical connection between artificial intelligence and practical teaching can be traced back to Skinner's work in the 1950s with the Smart Tutoring System, marking the inception of artificial intelligence in education (National Museum of American History, 2023; Yu & Lu, 2021). Later, machine learning systems based on big data emerged, representing the third phase of artificial intelligence evolution. Recent applications like ChatGPT, with natural language processing technologies, intensify interaction with technology, showcasing the ongoing evolution of artificial intelligence in education.

Artificial intelligence systems in education can be broadly classified into three categories:

1. **Expert Systems:** Software that mimics the work of individuals with expertise in artificial intelligence algorithms (Engelmore & Feigenbaum, 1993; Krishnamoorthy & Rajeev, 2018). These systems rely on knowledge and inference, necessitating a knowledge database related to the specific field.
2. **Intelligent Instructional Systems:** Originating in the 1970s, these systems form the mainstream of intelligent teaching, providing personalized

instruction based on a teacherless one-to-one teaching model (Lesgold, 1988; Mathan & Yeung, 2015). They represent a progression from computer-aided teaching (Balacheff, 2022).

3. **Dialogue-Based Systems:** Utilizing a dialogue-based method and fuzzy logic, these systems guide students through the learning process, offering personalized teaching (Ruan et al., 2019, Pai et al., 2021). The system evaluates student responses, provides feedback, identifies misconceptions, and offers explanations for correction (Ouyang et al., 2023).

Artificial Intelligence in Mathematics Education

The historical link between mathematics and artificial intelligence has been established positively, with artificial intelligence integrated into education using a non-routine problem-solving approach based on mathematical study and expert solution design (Richard et al., 2022).

Intelligent mathematical applications transform abstract mathematical knowledge into tangible representations, aiding human perception with physical reflections of mathematical properties (Balacheff, 2022; Lagrange, 2022). Artificial intelligence and mathematics share a symbiotic relationship, both relying on logic. While mathematics provides the foundational science for algorithm-based computing infrastructure, artificial intelligence can address mathematical problems efficiently, visualizing operations and analyses interactively and dynamically.

Despite the resistance of mathematics to technological change, artificial intelligence is poised to revolutionize mathematics education by automating processes traditionally prone to human error (Saralar-Aras et al., 2023). This shift may render the term “process error” obsolete, with technology-supported mathematics education programs contributing significantly to cognitive development and a deeper understanding of the world (Webel & Otten, 2016).

A 4-category taxonomy proposed by Van Vaerenbergh and Pérez-Suay (2022) sheds light on new artificial intelligence techniques in mathematics education:

1. **Information Extractor:** Takes observations from the real world and makes mathematical inferences.
2. **Reasoning Engine:** Draws logical conclusions from axioms found in the database.
3. **Descriptive:** Transforms solutions produced by the reasoning engine into understandable forms.
4. **Data-Driven Modelling:** Forms a database of student data, allowing various analyses, modeling, and tools related to the student.

For artificial intelligence integration in geometry teaching, addressing challenges such as developing a programming interface, establishing a standard format for information exchange, and enhancing databases with powerful search mechanisms is crucial (Quaresma, 2022). Artificial intelligence must work on understanding properties like joints and edges of objects and relationships between them, indicating the complexity of human intelligence.

Looking toward the future, expectations for artificial intelligence in education include collaborative work between teachers and artificial intelligence, providing personalized and inclusive education, educational equity, and lifelong learning. Artificial intelligence is anticipated to facilitate personalized and adaptive learning, focusing on students' core competencies, overall development, spirit, and happiness, fostering human-machine integration and promoting open and lifelong learning (Yu & Lu, 2021).

Artifical Intelligence Applications in Middle School Mathematics Education: An Overview

The integration of artificial intelligence into middle school mathematics education holds significant promise, offering robust and cost-effective tutoring solutions for students, especially those in private lessons (Bloom, 1984 as cited in Araya &

Marber, 2023; Font et al., 2022; Saralar-Aras et al., 2023). The effectiveness of artificial intelligence in education lies not solely in the technology itself but in the orchestration of its use and the dynamics of feedback loops (Balacheff, 2022).

A wide array of software, including MonuMAI, Antares, and Discourse Analytics (Clarke et al., 2018; Martínez-Sevilla & Alonso, 2022), is being developed with Microsoft Partners (2023) to create interdisciplinary teaching support tools. These tools analyze group dynamics and include applications such as learning analytics for communication insights, dyslexia apps for reading comprehension improvement, and platforms like FLEXA and the Beacon digital assistant designed to enhance personalized learning experiences (Courtois, 2019; Frattini, 2023).

Artificial intelligence (AI) applications in mathematics education can be broadly categorized into AI-based computational tools, AI-based expert systems, and intelligent teaching systems. This section discusses accessible examples of these systems: Assistments, Calculus Chatbot Sofia, PhotoMath, Ramanujan Machine, and Wolfram|Alpha.

Assisments

AssistMents (2023) serves as another illustration of artificial intelligence application in the realm of mathematics education. This particular tool aids teachers in furnishing valuable feedback to students, focusing particularly on the evaluation of open-ended questions. Developed with the specific purpose of assessing open-ended queries, AssistMents contributes to enhancing students' mathematical skills (Saralar-Aras, 2021). Consequently, it facilitates a more effective development of students' mathematical thinking abilities.

Designed for students across the primary, middle, and high school levels, AssistMents operates as a tool with a specialized focus on mathematics. Notably, it is offered as a free application, reinforcing its accessibility and commitment to fostering mathematical proficiency among students. This application's emphasis on open-ended question assessment and its complimentary availability position it as a valuable asset in promoting enhanced mathematical learning experiences for students across various educational levels.

Calculus Chatbot Sofia

Calculus Chatbot Sofia (2023) acts as an encyclopedia, offering explanatory definitions of mathematical terms and solving simple to complex math problems, interacting with computer algebra systems like Pari or Mathematica. Specifially, Calculus Chatbot Sofia, tailored for mathematics education, functions as an encyclopedia-like dictionary, providing elucidative definitions of mathematical terms. This innovative tool takes on the role of an expansive knowledge resource, offering comprehensive explanations to aid in the understanding of various mathematical concepts. Distinguished by its capacity to decipher intricate mathematical problems, Sofia excels in unraveling elementary as well as more complex mathematical equations.

In the realm of middle school education, Calculus Chatbot Sofia emerges as a resourceful companion for both students and educators. Its interactive capabilities extend beyond conventional definitions, enabling engagement with computer algebra systems like Pari or Mathematica (Saralar-Aras, 2021). This interaction empowers Sofia to tackle intricate mathematical problems, providing a versatile and adaptive solution to a spectrum of challenges. By facilitating interactions with sophisticated algebraic systems, Sofia becomes a valuable asset for mathematics students and teachers seeking effective responses to their inquiries.

Structured to cater to students across primary, middle, and high school levels, Calculus Chatbot Sofia offers its services through a subscription model. Positioned as a paid application, Sofia’s accessibility is complemented by its multifaceted utility, addressing the diverse needs of students undergoing mathematical education. In essence, Sofia’s capacity to explain mathematical terms, solve problems, and interact with advanced algebraic systems underlines its significance in enhancing the learning experiences of mathematics enthusiasts at various educational stages.

PhotoMath

Photomath (2023), a mobile app utilizing OCR technology, aids students in basic math, algebra, geometry, and more. It offers step-by-step explanations, visual aids, and animated tutorials. The paid plan, Photomath Plus, provides additional features like custom visual aids and detailed explanations for textbooks.

In detail, Photomath (PM) is a mobile app downloaded by over a million teachers globally. It utilizes OCR technology for image recognition and covers a range of mathematical topics, offering step-by-step explanations and animated tutorials. PM supports learning in basic math, algebra, geometry, statistics, calculus, and verbal problems, providing a personalized learning experience for students.

PM's interface involves scanning mathematical expressions, solving problems, and learning through step-by-step explanations. The app covers various mathematical concepts, and the paid plan, PM Plus, includes additional features like custom visual aids, detailed explanations for textbooks, and animated tutorials. The app aims to enhance students' mathematical skills and comprehension.

Ramanujan Machine

The Ramanujan Machine (2023), conceived as a tool, is dedicated to advancing the computation of irrational decimal numbers linked to significant mathematical constants like π or e. It endeavours to pioneer fresh calculation methods, steering away from repetitive patterns in favour of novel sequences. In essence, this application represents a notable leap forward in computing the decimal representations of these pivotal mathematical constants.

Delving into specifics, the Ramanujan Machine distinguishes itself as an inventive mathematical computation tool. It squarely tackles the complexities of irrational decimal numbers tied to fundamental mathematical constants. The overarching goal is to foster the evolution of inventive calculation methodologies, introducing distinctive sequences in place of predictable repetitions.

Tailored for middle and high school students, this application operates on a subscription basis, underscoring its specialized and advanced role in mathematics education.

Wolfram|Alpha

Wolfram|Alpha (2023), a computational engine, provides step-by-step solutions in response to natural language or mathematical queries. Its interface supports symbolic calculations and graphical representations, making it a versatile tool for various disciplines. Different pricing plans cater to various user categories, offering features such as extended calculation times and downloadable results.

In detail, Wolfram|Alpha (W|A) is a powerful computational engine developed by Wolfram Research. It provides answers to questions across various subjects, including mathematics, science, technology, society, and daily life. W|A employs natural language understanding and a vast database, offering step-by-step solutions rather than conventional web links. Its interface supports both symbolic calculations and graphical representations, making it a versatile tool for various disciplines (Yu & Lu, 2021).

Users can input questions in natural language or mathematical format, and W|A's fast and robust infrastructure, embedded with artificial intelligence semantic analysis technology, interprets and provides answers by cross-checking terms under thousands of topics. The interface includes tabs for different math topics, allowing users to select actions and input parameters for solving problems.

W|A offers different plans, such as “Pro” and “Pro Premium,” with features like step-by-step solutions, practical problems, guided calculators, extended calculation times, file size upload limits, and improved experiences for various user categories.

Navigating the Landscape of Artificial Intelligence in Education: Recommendations, Challenges, and Future Prospects

Recommendations have been proposed to address the challenges encountered or anticipated in the integration of Artificial Intelligence into education, with the underlying goal of enhancing teaching quality (Richard et al., 2022; Yang, 2021). Initiating improvements in education to elevate academic achievements and support learning outcomes necessitates an approach centered on the needs of both students and teachers (Luan et al., 2020; Richard et al., 2022).

Artificial intelligence applications in education accumulate vast amounts of data from diverse sources and platforms. The utilization of this diverse data and the establishment of connections among them enable targeted instructional strategies. Creating environments that harmonize data from various sources and defining the requisite standards are imperative, necessitating the development of novel methodologies for these processes (Güneş & Saralar-Aras, 2023; Yu & Lu, 2021). Ethical considerations, privacy concerns, transparency, and adherence to legislative criteria for data protection are essential obligations in data sharing, requiring the establishment of long-term trust-building mechanisms between humans and machines (Flores-Vivar & García-Peñalvo, 2023; Yu & Lu, 2021).

Effective problem-solving skills in artificial intelligence demand a well-organized reasoning ability. Modelling the intricate process of knowledge creation from cognitive and developmental psychology, which involves correlating diverse data types from different disciplines and interpreting student behavioural processes, represents a complex challenge (Shinohara, 2021; Van Vaerenbergh & Pérez-Suay, 2022). The multifaceted nature of human relations, characterized by continuous, dynamic brain activity over an extended history, makes the development of artificial intelligence's ability to extract meaning from these interactions a distant prospect.

In the context of mathematics education in Turkey, the integration of various technologies, such as computers and smart boards, faces challenges, hindering their routine incorporation as educational tools. Successful artificial intelligence operation necessitates flexibility to align with the natural course of mathematics teaching, allowing teachers to decide on its utilization (Richard et al., 2022; Saralar-Aras et al., 2023). The role of artificial intelligence in the classroom is a subject of debate, emphasizing the need for careful consideration of human rights and ethical concerns to maximize its benefits. Identifying the ethical and moral dimensions of addressing student and teacher needs through artificial intelligence requires ongoing feedback from stakeholders.

The expectation is for machines, including artificial intelligence, to adapt to humans rather than fundamentally changing human nature (see Freire et al., 2021; Mian et al., 2020). In this review, future developments in artificial intelligence are envisioned along three dimensions. Firstly, enhancing artificial intelligence's capability to analyze dimensional data, a challenging task for teachers. Secondly, creating artificial intelligence-powered virtual learning environments (metaverse) to offer real-time data reporting and personalized teaching tools, materials, and methods. Lastly, establishing Artificial intelligence paradigms that underscore processes like equality, participation, and cooperation in education, emphasizing their crucial role in maximizing the potential benefits of artificial intelligence.

Conclusion

In delving into the incorporation of artificial intelligence into education, this discussion introduces two readily accessible applications designed for middle school mathematics education, anticipating a surge in such initiatives over the past decade. Despite the ongoing assessments of developments and recommendations, a comprehensive evaluation remains imperative. Notably, artificial intelligence distinguishes itself by mirroring human attributes closely and progressively adopting a more human-like demeanour. Although it is envisioned that artificial intelligence could potentially replace human roles across various sectors, particularly in education, it is neither feasible nor advisable, given certain human characteristics. In the context of mathematics teaching, having artificial intelligence as an assistant to support educators in tasks such as assessment, exercises, assignments, and monitoring, while offering cognitive and affective insights, proves beneficial. Artificial intelligence can serve as a personal aide during students' extracurricular learning endeavours, offering support and providing information about their families, along with presenting student profiles based on analyses. Additionally, artificial intelligence can assist school administrators with diverse matters, from security to library utilization and performance evaluations. Nevertheless, challenges may arise due to incomplete integration, nascent developmental stages, and the multifaceted nature of data collection inherent in artificial intelligence. Therefore, it is imperative to establish high standards for swift integration and meticulous data management through human-supervised continuous control mechanisms.

The incorporation of artificial intelligence holds the promise of addressing both current and future challenges. However, concerns persist as various institutions and organizations highlight potential issues in their reports, identifying risk situations. Addressing these concerns necessitates large-scale studies, regulations, and policies developed in collaboration with various stakeholders in organized education (Center for Security and Emerging Technology, 2021; Department for Education, 2023; The European Commission, 2021). Algorithm-based processing procedures in human-machine interaction and reassuring interaction processes are critical. While the overall benefits of integrating artificial intelligence into mathematics education are apparent, the acceptance of artificial intelligence as a universally embraced technology in this domain remains debatable. Only time will reveal whether artificial intelligence can establish itself in the educational landscape, creating a classroom environment conducive to increased student engagement by handling repetitive tasks and alleviating the teacher's workload.

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Digital Transformation of Tech Universities: Understanding the Evolution with the Entrepreneurial University 3.0 Model

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Introduction

Universities, especially technical ones that develop according to the entrepreneurial type (University 3.0 models) become the core of the knowledge development system. It is necessary to create a favorable innovation environment in universities that will ensure effective interaction between participants in the innovation process at all stages of creating, developing, and implementing knowledge in order to commercialize it most effectively in the context of digital transformation.

To complete the project tasks, we conducted step-by-step analysis and research of the “University 1.0”, “University 2.0” and “University 3.0” models in the conditions of technical universities.

As part of the work, the authors analyzed the state of the scientific and innovative infrastructure of the technical university in the conditions of the “University 3.0” model.

Digital transformation is changing institutions and businesses around the world, but nowhere is digital transformation more evident than in universities. The drive for digital transformation in universities has been an important factor in enabling higher education institutions to thrive during the COVID-19 pandemic. But digital transformation is not just a response to the crisis. On the contrary, digital technologies will continue to transform teaching and learning, as interdisciplinary competencies become increasingly important, requiring specialists to adapt the skills and abilities acquired in various professions. The boundaries between functional levels are blurring, and improvement will be required for all technical professions.

As the world moves into the digital age, several terms have emerged. In most cases, these terms are used interchangeably. An example would be digitalization versus digitization and even digital transformation, which, although used interchangeably, are still completely different in nature. Primarily, these terms refer to different ways of responding to and absorbing new technologies. Therefore, it is crucial to understand the difference between digitalization and digitization.

While digitalization is about applying technology to existing business processes and workflows, digital transformation means reorienting these processes to a new, digital approach. Consequently, digital transformation is much broader, and digitalization and digitization are key components of any digital transformation initiative.

Universities, especially technical ones, that develop according to the entrepreneurial type (*University 3.0 models*) become the core of the system of knowledge development and its practical use. They accumulate highly qualified personnel who are able to perform complex interdisciplinary research and project work for enterprises and organizations and are also able to create a theoretical and scientific-applied base for the scientific and technological progress of the economy and society.

The globalization of the world economy and society leads to the fact that the creation or improvement of technologies and methods cannot be a source of competitive advantages for technical universities, enterprises or countries for a long time, but their constant development is necessary. The benefits of technological progress will be much broader and longer lasting if we ensure the formation of an innovative environment that ensures their constant involvement in innovation activities.

This paper is devoted to the development of ways to change the scientific and innovative infrastructure of a technical university in the digital economy. The paper considers problematic issues of the evolution of the institutional organization of modern higher education institutions in Uzbekistan in the context of digitalization of society. The main factors determining the process of qualitative change «of the "University 3.0" model» in changing educational spacesare considered. The problems of the issues studied in this paper reveal the peculiarity of qualitative changes in the development of the institutional organization of higher education institutions and represent an important direction of modern scientific reflection, which allows using the author's analytical conclusions in promising research on this topic.

Analysis of Scientific and Innovative Activities of the Technical University

The reason for different interpretations of the category "innovation" is the versatility of innovative phenomena. In a broad sense, the concept of "Innovation" reflects the result of a radical modernization of the technological foundations of production, and due to the fact that it is an innovation, it is characterized, first, by a high level of uncertainty of a certain economic entity, and secondly, by its long-term efficiency during its life cycle, that is, by the continuity of the innovation process. It follows that innovation combines originality and consistency.

The economic categories "innovation" and" innovation process" are close to each other, but do not coincide. The innovation process is a set of successive stages, such as the creation, adoption and dissemination of innovations, that is, a necessary component of a reproducible innovation system.

An analysis of global development trends shows that innovation, innovation activities and a knowledge-based or innovative economy play a key role in solving the full range of strategically important problems of various countries in the 21st century. The level of technological development is one of the most important factors determining the degree of socio-economic development of the state, its economic and political independence. The transition to the path of sustainable development of such countries as the United States, the European Union, Japan, and a number of Southeast Asian countries was achieved by expanding innovation processes in the real sector of the economy. Over the past 25-30 years, the number of people working in the innovation sector in the United States and Western Europe has increased by more than 2 times, and in Southeast Asia-by 4 times. In the European Union, the share of innovatively active industrial enterprises was more than 50%, although within the EU this indicator varies significantly for different countries. In the developed world, more than 75% of GDP growth is achieved through innovation. The effectiveness of innovations in these countries is based on the existence of a system-forming mechanism, named by K. Freeman “National Innovation System” (NIS), in his work on modeling technology policy in Japan. Noteworthy is the result of a survey conducted by the American Academy of Sciences, in which American economists recognized that the most outstanding event of the 20 century was the formation of a national innovation system. Although the last century was rich in various discoveries: jet aviation, television, nuclear power, space, the Internet…Why?

Because it is the national innovation system that is the mechanism that creates a process that allows you to meet any need of society.

Currently, Uzbekistan is undergoing an intensive process of forming a national innovation system. This is evidenced by the Decree of the President of the Republic of Uzbekistan “On approval of the strategy of innovative development of the Republic of Uzbekistan for 2022-2026” dated July 6, 2022 No. UP-165, aimed at accelerating innovative development in the republic, widespread introduction of innovations and technologies in all sectors of the economy, development of human capital, scientific and innovative spheres.

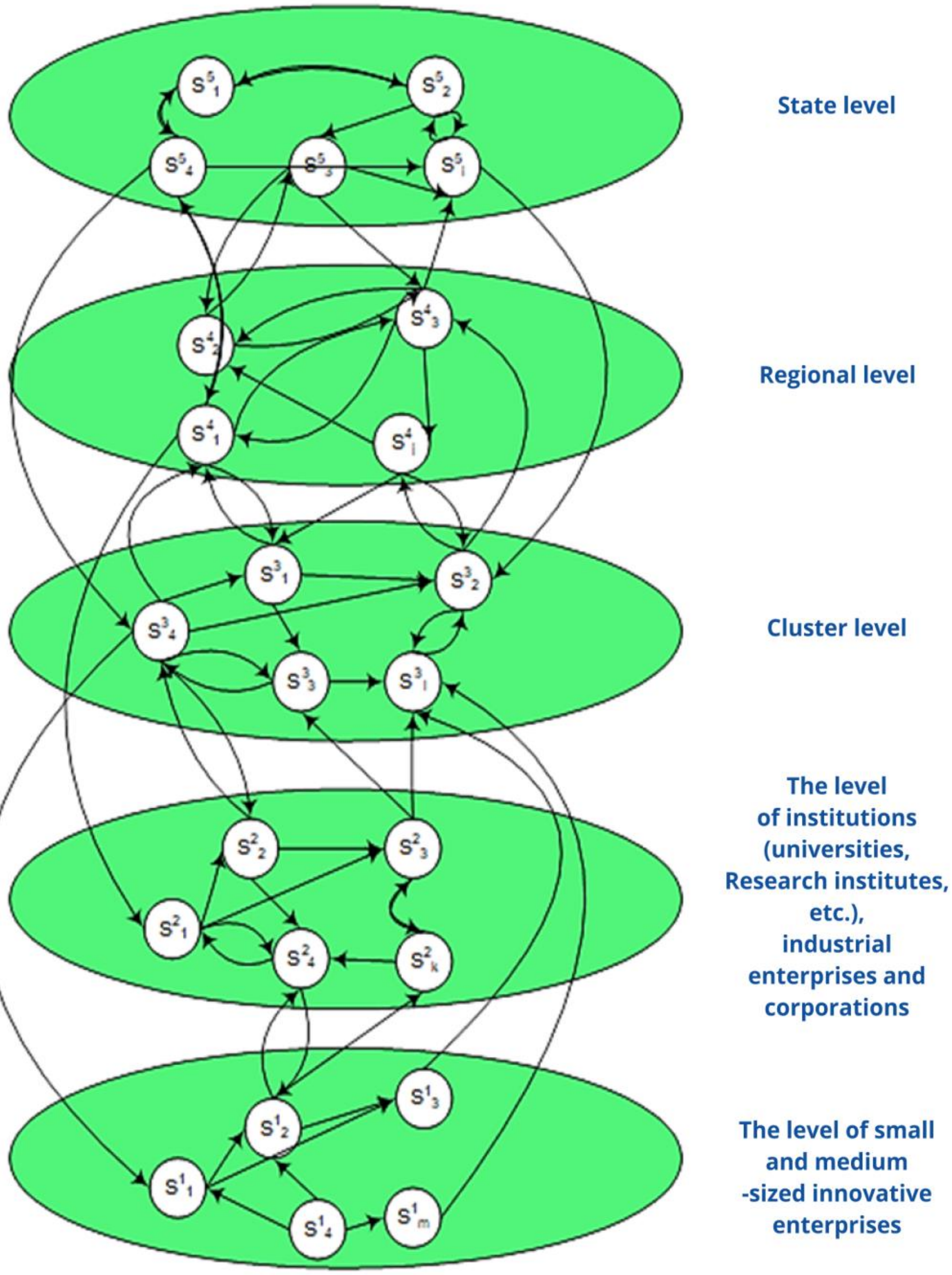

Figure-1 Fragment of the structure of the national innovation system

The Decree pays special attention to the need to increase the degree of commercialization of scientific and innovative developments, the level of cooperation between science, education and industry in the real sector of the economy.

Innovation centers and small and medium-sized innovative enterprises can and should play an important role in solving these complex tasks (Figure 1).

There are great opportunities for small innovation centers, which, unfortunately, are extremely insufficient today. What mechanisms should be used to fill this niche of the innovation infrastructure formed by the National Innovation System is a separate issue that requires in-depth analysis. Let us note only one aspect of the problem related to the central role of enterprises in the innovation process: multi-faceted innovation centers with a developed scientific component can produce knowledge and even stimulate demand for it, offering new, previously unknown technologies, the mastery of which ensures the strengthening of specific positions of enterprises, but it is the latter that carry out the practical implementation of innovations, their promotion to consumers and the formation of feedback.

Sharing the practice of developing technical universities in the post-Soviet space and in foreign countries, as already noted, allows us to draw a conclusion about the practical implementation of various institutional models of a modern technical university: "University 1.0, 2.0, 3.0, 4.0", including the theoretical development of the" University 5.0 " model.

At the same time, the model of a modern technical university is understood as an ideal and generally presented multicomponent and multi-level structure of a higher education institution that performs its historically determined role and normatively defined functions in the education system and in society.

In the provisions ofих analytical reportsand government documents on the implementation of thestrategy for sustainable socio-economic development of the Republic of Uzbekistan for theperiod up to 2030, the recommendation part notes the expediency of improving the activities of universities based on the "University 3.0" development model and the transition to a network system of higher education institutions through clustering (formation of educational complexes – clusters that unite institutions of various levels of education).

World experience shows that the “University 1.0” model existing in the traditional education system is limited to teaching, including teaching and research.

Since the introduction of the new public administration system in higher education at the end of the twentieth century, the management approach, which includes quality assurance systems used in industry and enterprises, has been increasingly applied in the non-profit and public sectors. National governments and universities have followed this path. In addition to the large institutional and financial autonomy of a number of States, they have developed public accountability and quality assurance systems to ensure that technical higher education and research institutions meet national and international standards. Technical universities began to take part in open international and national competitions in order to receive additional funding (mainly models “University 2.0, University 3.0”).

Because of this ambiguity, an independent culture of pedagogy - innovative pedagogy-is rapidly developing today.

A special feature of innovative education is to increase the student’s sense of responsibility and self-confidence in the future (Figure 2).

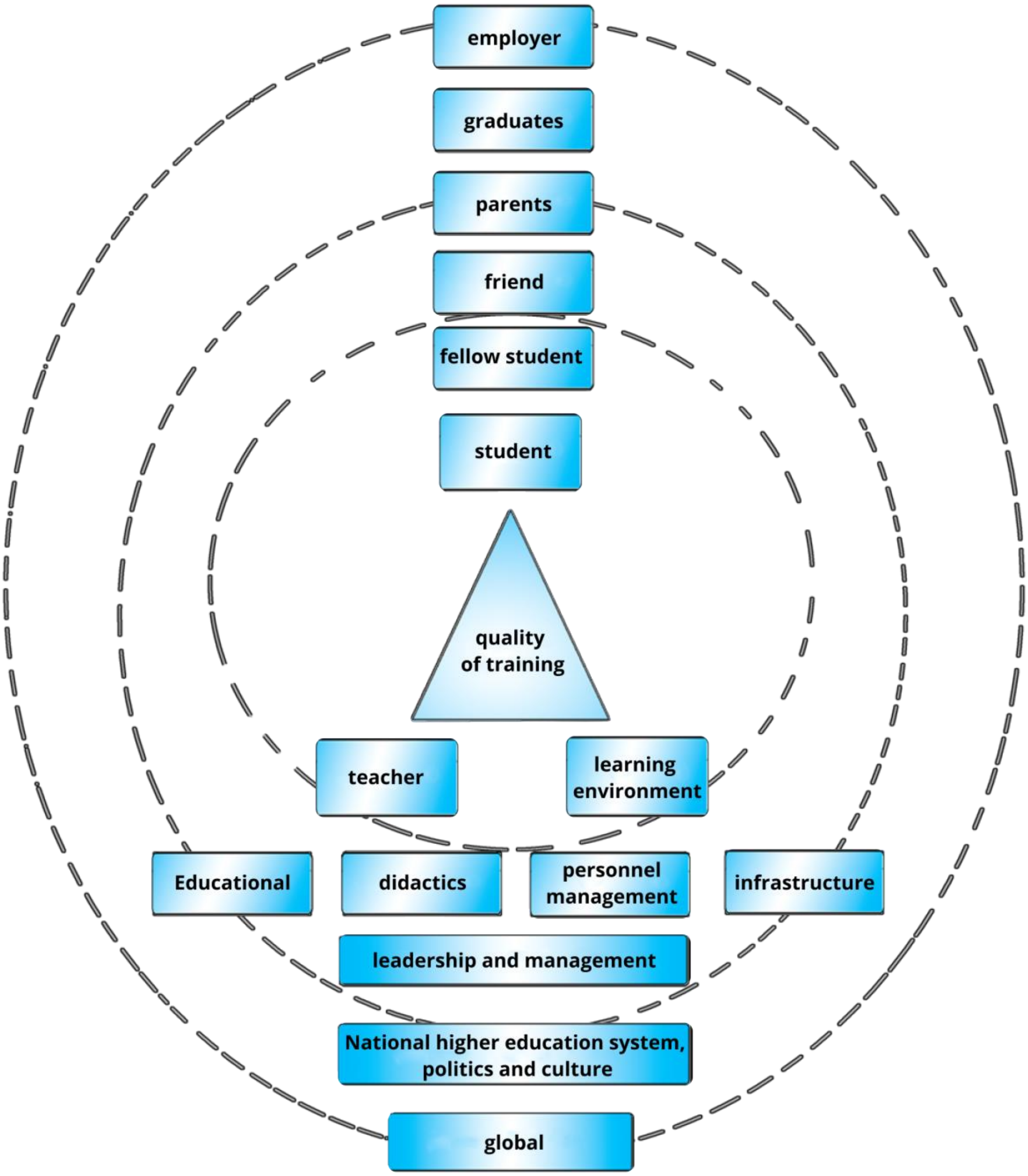

Figure UNOC-2 Participants and factors influencing the quality of education in technical universities

The University 3.0 model meets the needs of the post-industrial stage of social development, focused on innovations and the needs of the knowledge industry, the development and application of innovative technologies and technical solutions in a new high-tech production (transition to the digital industry, miniaturization in electronics, production automation, creation of high-performance computers, microchips and automated systems, production of materials with specified properties, etc.). etc.), as well as the growth of the service sector and consumption. The processes of social development actualize the increasing role of universities in the development of human capital, in the formation and development of specialists with such universal competencies that allow them to effectively carry out professional activities in various fields.

Within the framework of the described model, the university is an institution of higher education of an entrepreneurial type – entrepreneurial based on the results of the creation of innovative companies and entrepreneurial by the nature of the interactions of the management team - managers – university management and business representatives. At this stage of the development of its institutional evolution, the university strives to attract additional investment, intensively uses innovative technologies in the pedagogical process and closely interacts with businesses interested in the practice-oriented developments of university scientists. In the implemented institutional model “University 3.0” creates favorable conditions for the formation of high-tech start-ups and spin-off companies with the participation of students and teachers. Along with the cultural, educational and research functions already traditional for its activities, the institution of higher education performs the function of transferring advanced technologies that it commercializes. The University is becoming a powerful research center that, in the conditions of clustering, produces for the needs of the market those innovative technologies and products that are demanded by the consumer. In terms of material equipment, the University 3.0 includes in its structure, along with classrooms, laboratories and libraries, business incubators and technology parks, design bureaus, project offices and exhibition centers.

By attracting investment, the university is increasingly striving to be financially independent of the state. At the same time, the integrating function of the university institutional organizationt model 3.0 is not only to play an active role in the processes related to the commercialization of technologies and technical solutions, but also in the development of business structures through their integration and consolidation, as well as the formation of new markets. A classic example of the implementation of the model of such a university is Stanford University and the “silicon valley” formed with its participation.

Within the framework of the “University 3.0” model in the history of education, a transition to a new educational paradigm “Education through life” is being carried out, which naturally cannot but strengthen the position of universities as system-forming centers of continuing education that promptly respond to requests for training or retraining of specialists necessary for the labor market.

Modernization of the higher education system (visual modern – updated, modern, fast-growing) requires a relatively innovative approach to education:

- the need to develop professional and innovative competence of the teacher in relation to the development and implementation of pedagogical innovations;

- commercialization of research activities and innovative approach to education.

These innovations and transformations require constant study, analysis and generalization of the best pedagogical experience in implementing commercialization and innovation in higher education in countries such as China, Japan, Korea, the United Kingdom, etc.

The future society is a society of knowledge and innovation. The main function of a modern technical university is to train innovators. An important form of entrepreneurship is knowledge-based entrepreneurship based on the integrationof science, education and culture. For this reason, the concept of intellectual entrepreneurship is being developed today.

The essence of project-based learning: the student must be able to perform useful, thoughtful work, perform real tasks in the field of their future career, and communicate their solutions to real consumers. This requires that the learning process be carried out in the same way as designing a situation of uncertainty. The teacher should create the conditions for this, and the student should be the builder of their knowledge, not the recipient of information. The student must move from “mastering” knowledge to “creating”, that is, to the standards of “think-design – implement-manage”.

Analysis of Socio-Economic Conditions of Digital Change in Scientific and Innovative Activity

The social impact of an entrepreneurial innovative approach to education in the context of globalization, as well as the socio-pedagogical impact of an innovative approach to education in the context of globalization, is changing dramatically (and in the era of the destruction of the unipolar world in which we now find ourselves, it is likely to undergo huge structural and politicized changes):

1. Scientific and technological progress and socio-economic renewal of the continuing education system, studying the best practices of higher education, applying innovative approaches to education and using information technologies;
2. Introduction tothe practice of a comprehensive organizational form of technical-oriented training, which serves to develop the level of knowledge, intellectual abilities, social activity, and creativity of students;
3. The need to develop professional and innovative competence of the teacher in relation to the development and implementation of pedagogical innovations;
4. Commercialization of research activities, innovative approach to education is based on the fact that the content and result of education are personality-oriented, the content, form, method and vocabulary of education are based on the latest achievements of science and technology (Figure - 3).

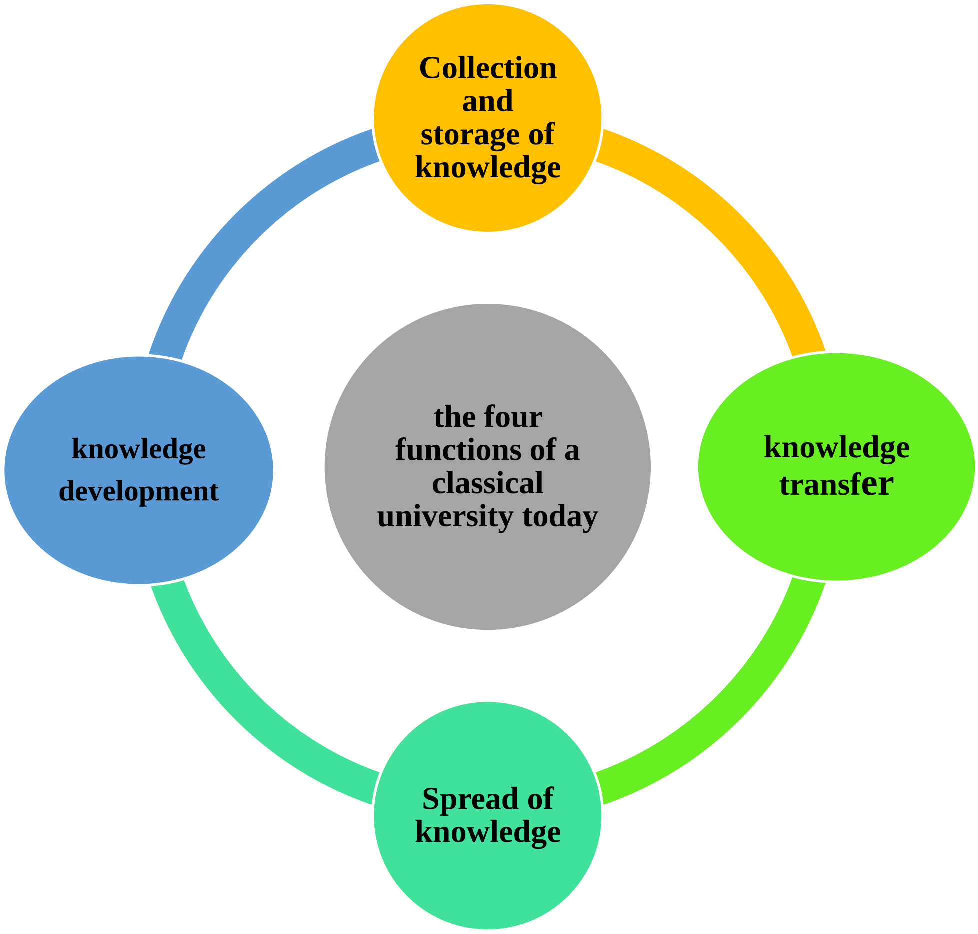

Figure 3. Functions of a classical University

These innovations and transformations require constant study, analysis and generalization of advanced pedagogical experience in implementing commercialization and innovation in higher education in countries such as China, Japan, Korea, Great Britain, etc., as well as using the achievements of pedagogical and psychological science in practice, using modern pedagogical and information and communication technologies.

Teaching methodology – is a system of teacher-student relationships that ensures the assimilation of the content of education.

The teaching methodology is considered the main part of the learning process and characterizes the interdependence of students in the educational process, so without the appropriate methodology, it is impossible to carry out purposeful educational activities.

How to use interactive learning methods in a group.

As a practical direction of modern pedagogical and psychological research today, several teaching methods in pedagogy are distinguished:

1. Passive – the learner acts as an” object “ of learning (listening and playing).
2. Active – the student shows himself as a primitive learner (independent work, creative tasks);
3. Interactive - mutual cooperation between teachers and students. Such a group of students can be divided into “student-teacher” and “student-student”. In interactive learning, the teacher is an active organizer of learning activities, and the student manifests himself as the elbow of this activity.

Interactive learning is the most effective organizational form of developing cognitive activity, characterized by the transformation of the student from an object of learning in interactive learning to a subject of self-integration.

Interactive learning not only develops students activity, creativity and independence in obtaining information, but also provides comprehensive support in the implementation of educational goals.

Closing the modern system of higher education in our country, of course, requires the full use of advanced technologies from all over the world.

Today, advanced educational technologies are divided into 4 groups:

1. Problematic technology.
2. Didactic game technology.
3. Technology Collaboration.
4. Modular technology.

A modern university is an active, multi-faceted and effective institution of society, which must simultaneously solve the following three main tasks:

1. the task of education;
2. the task of scientific research;
3. the task of innovative entrepreneurship.

The main aspects of the University of Entrepreneurship:

First, entrepreneurial universities are engaged in social entrepreneurship. The essence of the University of Entrepreneurship can even be classified according to the following 4 aspects, highlighted by Yu. Schumpeter (1883-1950):

1. ccommitment to innovation;
2. ability to take risks.
3. self-confidence.
4. feel independent.

The entrepreneur engages in "creative destruction" and implements new combinations of resources.

Secondly, it has a multi-channel system of financing its activities. Its main sources are:

1. Implementation of educational services,
2. Publication and sale of educational and methodical literature,
3. Raising funds from businesses through participation in joint commercial projects,
4. Revenue from the implementation of regional orders,
5. Government orders,
6. Graduates,
7. International charitable (sponsorship, charitable) organizations,
8. Fundraising (fundraising for various purposes),
9. Endowment (charitable investment fund, very important support of the university community).

Third, it constantly promotes initiatives to participate in new activities, such as strengthening competitiveness and diversification of activities, and improving marketing services.

Fourth, he performs a profound transformation in accordance with his inner strength (constant). Entrepreneurship University -is an ambitious goal+effective organizational change. An entrepreneurial organization will need a new balance between science, education, and innovation.

Fifth, it takes interaction with the external environment to a new level, adding international relations.

The University of Business consists of:

- First, the university is an entrepreneur within the framework of its mission.
- Secondly, the university is an innovator. Its subjects are innovative, its activities are innovative, and its products are innovative.
- Third, the university is an integrator. The activities of all its subjects are focused on the final result and are carried out synchronously with the regional community. It is a member of "strategic associations" in cooperation with leading domestic and foreign universities.

Key features of University 3.0:

- extensive cooperation with industrial companies, investors, venture funds, large corporations, scientific organizations and other universities,
- the main task of a new generation university is the formation and commercialization of knowledge,
- a adaptive selection (competition) for the best specialists, students and research contracts,
- in high international ratings,
- the policy of globalization - teaching is conducted in English,
- reducing the burden of public administration and intervention.

The state University continues to fund 3.0, but funding will be provided through third-party tools to reduce the impact of research and policy development. The University also receives funding from alumni and charitable sponsors. Table 1 provides a comparative description of university concepts.

Table 1. Anequal odescription of university concepts

	University 1.0	**University 2.0**	**University 3.0**
	Medieval Europe gumboldt	research	Entrepreneurship
purpose	Education	Education, research	Education, research, commercialization
Research methods	Educational to *	content * Aimed at monophanes	Multi-discipline, Interdisciplinary
Language of Instruction	Latin (NY)	National Languages	English
Graduates	Professionals Specialists	Researchers	Professionals, Researchers, Technology Entrepreneurs
Non-structural units	Schools, Faculties, Colleges	Faculties, Departments	Institutes, HEIs, Universities, Academies
Supervisor, requirement	Rector	Professor	Professional Managers
Degree of Influence	Local	National	International
Tidying	up Autonomous	State	Autonomous
Level of Educational Opportunities	Massa	Elita	Popular and elite

The University of Entrepreneurship includes two organizational areas: scientific and educational and entrepreneurial and solves two tasks: the first is training future entrepreneurs, and the second is an entrepreneur-innovator (Figure 4)

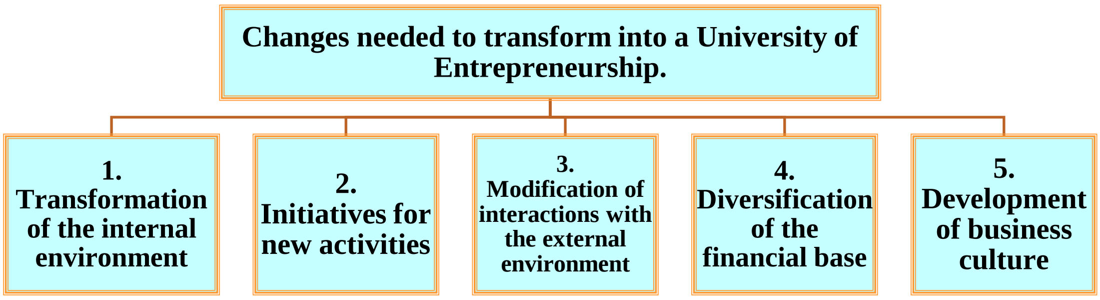

Figure 4. Stages of change for transition to University-Entrepreneurship (3.0)

The future society is a society of knowledge and innovation. The main function of a modern technical university is to train innovators. An important form of entrepreneurship is knowledge-based entrepreneurship based on the integration of science, education and culture. For this reason, the concept of intellectual entrepreneurship is being developed today.

High-quality educational services in modern conditions are achieved only through the active participation of teachers not only in the educational process, but also in scientific, advisory and innovative activities.

“Commercialization oftechnologies” is a process in which research results are transformed into goods and services on the market. The results of commercialization will bring not only financial benefits in the form of investment in research, but also in the form of expanding production, improving its quality and reducing the cost of production.

“Technology commercialization” is a form of technology transfer in which the consumer (buyer) obtains the right to use knowledge and pays it to the owner (developer of the technology) in one form or another in the amount established by the terms of the license (or other) agreement.

The goal of commercializing the results of intellectual activity is to better meet the needs of:

Educational institution-in the conditions of life and development of its teaching staff, in the training of highly qualified specialists.

in society - in the expanded reproduction of personal and intellectual potential.

In order to become a business university, first of all, the basic conditions that are closely related to the university charter are included - creating goals, there must be concepts, including: transition from a vertical university to a police university; promote the model of knowledge dissemination throughout the community, cultural change through an innovative program.

Since the University of Entrepreneurship focuses primarily on applied research and innovation, teachers are required to go beyond theoretical questions and study the real-world strategies and practices of successful corporations and countries. The innovative potential of scientific activity is a priority in the development of a market economy.

Research results are reflected in products and services. The research areas of the University of Entrepreneurship, in turn, can be divided into two, namely engineering and social and humanitarian.

The main thing is to create a creative, innovative and entrepreneurial atmosphere for teachers and students in such universities. There is evidence that science is turning into money. Innovation means turning knowledge into big money. The problem we face in this regard is that knowledge does not translate into money. That is why the issue of developing a new type of innovative thinking, where managers at all levels can use innovative and project support, is on the agenda today. The solution is to create a new institute-the club of “ professors-entrepreneurs “(founders). It will also be necessary to solve such issues as organizing free consultations, business modules and seminars, training programs, and forming an interdisciplinary accelerator class.

In the context of a globalized market, it is important to learn how to commercialize your ideas and developments.

In the United States, for example, the ability to expand new knowledge and projects is secondary. On the contrary, knowing how to negotiate, collaborate, and find partners to commercialize your business is a key link in the innovation chain. It is a rare case when one person has both entrepreneurial and research abilities-the basis for creating a high-tech business.

In a classical university, relations with the environment are episodic and have a predominantly vertical form. One of the most important aspects of the University of Entrepreneurship is its desire to constantly accelerate and diversify its interaction with the external environment, including international relations. Today, innovation in education also means integration.

The University of Entrepreneurship interacts with 2 organizations: research and education and solves 2 tasks: 1) prepares future entrepreneurs and 2) shows himself as an innovative entrepreneur.

The University of Entrepreneurship affects the environment through two factors: innovative and intellectual potential and entrepreneurial initiative (creative software and students). Henry Itzkowitz "Triple Helix**": - "**In the model, government, business and education are closely intertwined, with the university playing a key role." In other words, a three – pronged approach is being launched: market dynamics – dynamics of knowledge creation-dynamics of political and legislative acts in the field of innovation, the "fourth spiral", i.e. cooperation of the university with the state, business and technology parks (as representing the interests of consumers). The only way to develop an Entrepreneurship University is through training and mutually beneficial cooperation with strategic partners-universities, technology platforms, innovation zones, clusters, the state, and state corporations.

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Nanotechnology: Nano Measures with Giga Implications for Education

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Introduction

Nanotechnology, or nanoscience, is an emerging field of study that is interrelated with science, engineering and mathematics. Nanotechnology presents a number of useful applications for everyday use and applications as we bridge the twenty-first century with the twenty-second. In this chapter, the authors postulate not only a number of everyday uses and applications for nanotechnology, but also provide historical contexts and future possibilities for elementary education, secondary education, and higher education.

The prefix "nano" derives from the Greek language, meaning *very small*. Nano is defined as one-billionth of a meter and is akin to the ratio of a tennis ball to the size of Earth (Rafique et al., 2020; Taha et al., 2022). The nanoscale and nanoparticles are considered as anything measured at, or less than, 100 nanometers (nm) (Bayda et al., 2019). For reference, there are 1 million nanometers in a single millimeter (Figure 1).

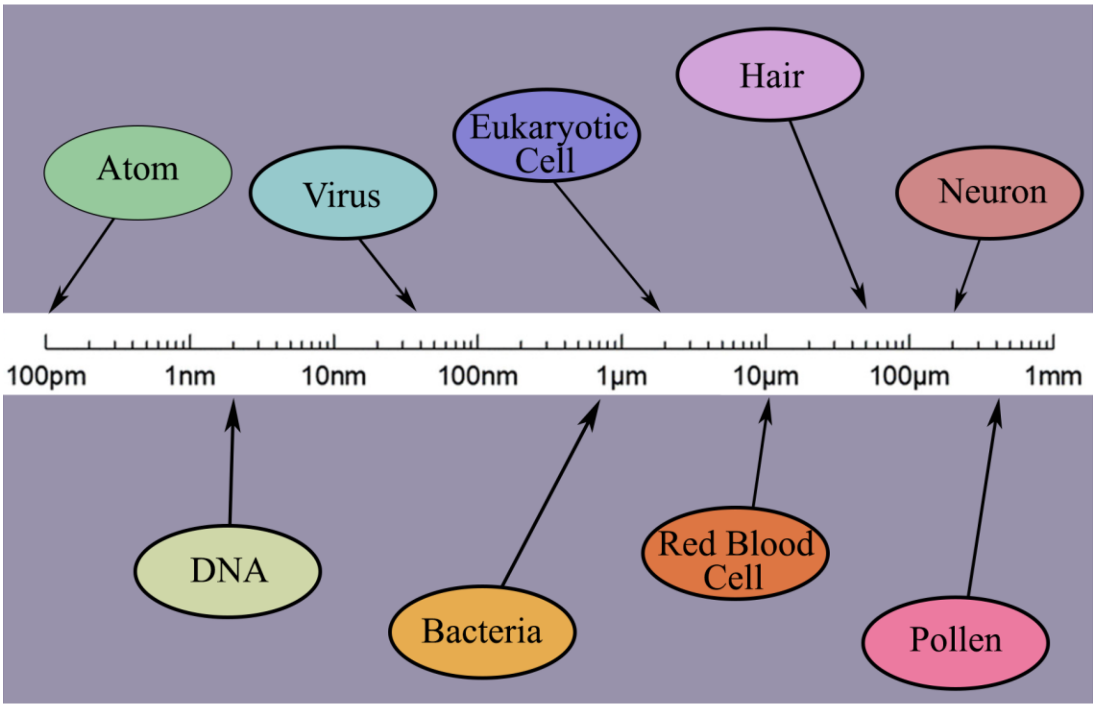

Figure 1. A comparison of the nanoscale

The field of nanoscience and nanotechnology combines the fields of biology, chemistry and materials sciences (Mitin et al., 2008; Rafique et al., 2020). Interestingly, engineered nanoparticles can have different compositions and effects in comparison to the same exact materials at a larger scale. There are potential unseen risks for humans and other living things dependent on the manner in which nanotechnology is employed (Rafique et al., 2020). The structure and function of nanoparticles is dependent on their shape, size, inner characteristics and surface characteristics (Mitin et al., 2008). Nanoparticles can either remain free or grouped together based on their chemical properties (Rafique et al., 2020; Taha et al., 2022). Nanoparticles can also be formed though industrial means or by breaking down larger particles. Despite its name, nanotechnology does not only refer to working in smaller dimensions; it involves altering the molecular properties of materials to alter its structure and function to the best desired properties of the respective material.

Just as with all scientific disciplines, there are a variety of different classifications of nanomaterials; the first being natural vs. artificial nanomaterials. Natural nanomaterials, as the name implies, are naturally occurring in nature; examples of such being particles in smoke or the particles that make up our cells (Griffin et al., 2017). Viruses are another commonly, naturally occurring nanoparticle that goes unknown to most (Taha et al., 2022). Lozano (2022) defines artificial nanomaterials as those that are man made, such as particles from vehicle exhaust or particles from medicines created by scientists. In the 1920s, tire companies used the nanoparticle, Carbon Black, to improve the performance of their tires without knowing of the existence of nanoparticles (Taha et al., 2022). Another dichotomy of nanomaterial classification comes in the form of Fullerenes and Nanoparticles. Fullerenes are allotropes, or different forms of the same element, of carbon. Some examples of Fullerenes that are familiar to most would be diamond or graphite. Nanoparticles can include Fullerenes but also include the nanoscale version of other elements such as gold or silicon (Lozano, 2022).

Perspectives in Progress

The origins of nanotechnology are widely debated amongst the scientific community. Richard Feynman is considered to be the pioneer scientist in the field of nanoscience when he introduced the concept in 1959 (Bayda et al., 2019; Rafique et al., 2020). Looking back throughout history, it was found that other scientists had worked with nanoparticles. Sixteenth century Swiss physician, Theophrastus von Hoenheim, had used gold nanoparticles to treat his patients and John Utynam had patented a gold nanoparticle-based glass in 1449 (Bayda et al., 2019; Rafique et al., 2020).

The concept of the nanometer was introduced in 1925 by Richard Zsigmondy, who would go on to win a Nobel Prize in the field of Chemistry. The term "nanotechnology" was coined in 1974 by Norio Taniguchi to describe nano-sized materials (Rafique et al., 2020). It is fair to say, even with nanoparticle uses and recent advances, the field of nanotechnology and nanoscience is not a new field of study. Although it is not a new field, it is still leading to and making great strides in the fields of science, technology, engineering, and industry (Mitin et al., 2008).

Nanotechnological Applications

Unbeknownst to many, nanotechnology has a variety of uses. In the field of material sciences, nanotechnology is applied to improve material properties, such as friction, wear, or adhesion. According to Rafique et al. (2020), nanoparticle materials illustrate different and superior qualities, in comparison to traditional materials, such as, but not limited to, enhanced ductility, flexibility, wear resistance, and magnetic properties. The use of nanotechnology to engineer different atomic sizes, structures, and surface areas also allows for the alteration of melting points for different materials. An increase in atomic surface area can lead to an increase in the melting point of a material while decreasing the surface area will have an inverse effect. The surface area of nanoparticles also has an effect on the electrical conductivity, as smaller surface areas lead to greater electrical conductivity. Materials manufactured using nanoparticles were shown to have 10 times the thermal conductivity than that of metal (Ikumapayi et al., 2021).

Mechanical properties of material can be defined on the basis of different factors such as strength, hardness, the ability to penetrate other materials, resistance to deformation when affected by outside forces, and how much weight a material can bear (Rafique et al., 2020). Smaller nanoparticles have been found to possess greater levels of mechanical properties; strength in particular. Ikumapayi et al. (2021) also noted in their research that materials manufactured with nanoparticles could withstand extreme strain and were very strong. Nanoparticles of sizes less than 15 nm were found to be superparamagnetic. For reference, paramagnetism is defined as being attracted by a magnetic field but not retaining magnetic properties when removed from the magnetic field. In terms of elasticity, the strength of the bonds between nanoparticles directly correlates with the elasticity of the respective material.

In the biomedical field, nanotechnology, called nanomedicines, have been employed to improve drug design and targeting along with uses such as the artificial development of human tissue. Nanotechnologies have been found to be useful in treating pulmonary patients (Doroudian et al., 2021). The researchers found that nanomedicines were able to better target specific areas of treatment for patients, which led to lessened recovery times than traditional medicines. The nanomedicines were engineered to respond to internal or external stimuli, such as temperature or pH, to allow for a controlled, precise release of the therapeutic treatment to the specific targeted sites. These nanomedicines are not limited to respiratory ailments. Nanomedicines have also been found useful in the treatment of cancer. Additionally, Grodzinski et al. (2019) also found that the precise targeting of the medicines to the areas of ailment had led to increased rates of recovery and more efficient treatment. Nanomedicine has also been utilized for bone regeneration and appetite control (Ikumapayi et al., 2021). These are a few examples and highlights of its uses and successes. Nanomedicine likely possesses an immense upside and may lead to much improved recovery and treatment of patients for a variety of medical conditions.

Contemporary Uses

Nanotechnology is currently in use in consumer products and the industrial sector in items such as sunblock, paints, dyes, and cosmetics. The nanoparticles used in cosmetics and sunblock allows manufacturers to alter product designs to the specification and preferences of their respective clientele. The nanoparticles used in sunscreen, titanium dioxide and zinc oxide, provide a higher degree of consistent protection from harmful UV radiation (Lozano, 2022). These nanomaterials offer better light reflection for a longer time period.

A study by Ikumapayi et al. (2021) notes that nanotechnologies can be employed in food packaging to determine whether or not the products have been contaminated. Nanotechnologies can also be employed to alter the flavor of foods, as nanoparticles can be applied to target cells on taste buds to enhance or block specific flavor profiles. Another example of how nanotechnology has affected food is in the "spreadability" of condiments. The increased surface area of the nanoparticles has allowed for mayonnaise to be easier spread on bread (Lozano, 2022).

One of the biggest fields that nanotechnology has made an impact in is the field of electronics. Whereas in the past semiconductors were utilized, nanotechnologies have advanced the features of currently existing technologies in features such as image resolutions. In the aspect of computing, the sheer size of nanotechnology has allowed for advances in features such as memory and processing speeds. Interestingly enough, the industry of creating microtechnologies and microfabrication began in the electronics industry (Ikumapayi et al., 2021). Microfabrication devices typically refer to items such as integrated circuit technologies and micromachining and are typically silicon wafers. These microtechnologies also include products such as smart phones, integrated circuits, solar panels, semiconductors, and flat panel displays. The sizes of these products are measured in micrometers, which is even smaller than a nanometer. In today's world, microfabrication is being combined with nanotechnology to produce new and higher quality products (Ikumapayi et al., 2021).

Economic Implications

Provided the aforementioned development and uses of nanotechnologies, it is paramount to address its economic implications. The innovations of nanotechnology allows for the creation of more job opportunities. The nanotechnology sector allows for jobs that move away from demanding physical labor, to tasks requiring a more technologically literate skill set. Today's society is moving more towards the mastery of a technological-based skill set and away from traditional manual labor and manufacturing jobs of the past. The current trend in which our society, workforce, and educational focus is currently working towards benefits future jobs that will arise from the nanotechnology industry. Recent projections of the nanotechnology industry suggest that the total worldwide market will exceed 40 billion dollars by the end of this decade (Adam & Youseff, 2019). As of 2018, the nanotechnology industry in Europe and the United States were able to generate $941 million and $903 million in gross revenue, respectively (Talebian et al., 2021). Given the immense revenue generated from this industry, it is reasonable to predict the growth, creation, and future needs for technological skill-sets required for nanotechnological positions.

Building the Foundation: Elementary Education

Introducing nanoscience in primary school provides young learners with opportunities to conceptualize and make connections to nano measures. Teacher facilitated guidance and the utilization of interactive activities supports students in developing basic nanoscience terminology and basic nanometer measures related to how matter acts in minute scales (Mandrikas et al., 2020). While many nanoscience concepts are rather abstract, there are a variety of approaches teachers can employ to help students conceptualize and connect for understanding. Modeling nano surfaces and water interactions provided hands-on, experiential learning for students of all backgrounds (Kolb et al., 1984; Mandrikas et al., 2020; Vygotsky, 1978). Providing young learners with real world connections and assisting students with social avenues for learning in context are additional strategies teachers can employ for bridging connections via discovery learning (Dewey, 1916; Piaget, 1933). Most importantly, providing exposure to young learners paves pathways and provides background knowledge students can employ towards more complex learning as they progress in grade levels from high school through higher education courses (Mandrikas et al., 2020).

The use of real-world connections concerning size, shape, and scale of visible, concrete objects at the primary level undergirds later nanoscience concepts that can be introduced in lower and upper secondary school. Additionally, inquiry-driven, hands-on learning experiences introduce and train students on a classroom structure and framework that is essential for further scientific discovery (Jesionkowska et al., 2020; Lati et al., 2019). The similarity in classroom structure can provide a consistent background as students move from concrete objects and interactions in elementary school to more abstract concepts introduced in middle and high school. Good design will embed these learning progressions within both elementary and secondary school curriculum in a systematic and developmentally appropriate manner.

Building the Structure: Secondary Education

As with primary school settings, hands-on activities with manipulatives, analogies, and models enables secondary school students to grasp abstract nanoscale phenomena not accessible through direct observation (Stavrou et al., 2015). Additionally, relating nanotechnology applications to everyday applications through group interactions and experiential learning settings makes the learning relevant and meaningful (Kolb, 1984; Vygotsky, 1978). Employing cooperative group settings and beginning with macroscale observations about the world first leading into nanoscale phenomenon provides connections for knowledge. These pro-social interactions forge supportive social networks, forming linkages for cognition (Stavrou, et al., 2015; Vygotsky, 1978). Students can learn about the interconnections between science, technology, engineering, and society through discussing real-world applications and societal impacts of scientific discoveries and emerging technologies. Discussing the applications and societal impacts of nanotechnology enables students to appreciate and construct meaning with respect to the interconnections between science, technology and society (Stavrou, et al., 2015). The combination of understanding societal impacts, increasing scientific literacy, and expanding potential career opportunities are all justifications for expanding nanoscience education in secondary schools (Figure 2).

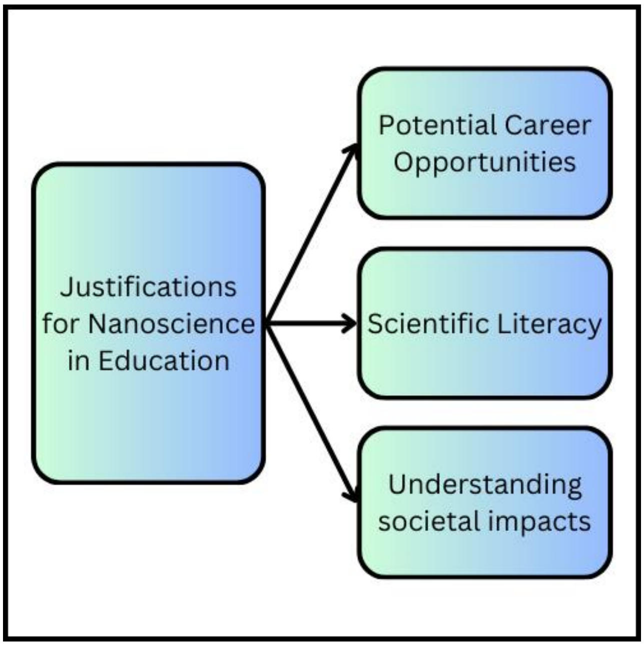

Figure 2. Justifications for nanoscience education

Nanotechnology is a sector which holds value in many different types of industries. High school is the bridge between primary school and higher education that prepares students for future workforce qualifications. School-aged students typically begin to consider future careers when they enter secondary school during ninth grade. The progression of science classes in secondary schools in the United States typically begins with general science or biology in the first year of high school, followed by chemistry and then physics or another science elective (DeBoer, 2019). The current section will explore the potential preparations that secondary science educators can take to provoke interests in students for considering a future career in the nanotechnology sector.

Biology and chemistry are typically taught to students in their ninth or tenth grade years, respectively, and are usually the initial scientific classes offered to secondary education students (DeBoer, 2019). Typically, introductory biological and chemistry coursework does not cover nanoparticles and nanotechnology. Nanotechnology may be covered in physics curricula but is not a component of biology and chemistry units (Ipek et al., 2020). This may also be due to the fact that the field of nanotechnology is relatively new and has not made its way into mainstream scientific curriculum. Another challenged faced by secondary educators in integrating nanotechnology into the curricula is the interdisciplinary nature and the unique functionality of matter at the nanoscale (Feldman-Maggor et al., 2022). Along with the topic of nanotechnology not making its way into mainstream scientific curricula, it has been found that most secondary education teachers of all disciplines, biology, chemistry and physics, have not developed proficiency in the topic of nanotechnology (Ipek et al., 2020).

The lack of exposure can be attested to a number of reasons. The first challenge faced is deficiency of knowledge on the topic by scientific instructors and the lack of exposure to nanotechnology in mainstream secondary scientific curricula. According to Ipek et al. (2020), teachers who undertook in-service training or courses in nanotechnology had significantly higher awareness in that area than teachers who did not. It is also important to note that the topic of nanotechnology is not usually taught to preservice science teacher candidates in university teacher preparatory programs (Feldman-Maggor et al., 2022). Including nanotechnology would significantly improve the understanding of the topic for instructors, which would lead to greater comprehension and understanding for students taught by future instructors.

Along with proper science teacher preparation in the topic of nanotechnology, an adjustment in scientific curricula must be made accordingly in order to properly accommodate the future demand of jobs in the nanotechnology field. Literary research by Peters-Burton et al. (2014) fielded a set of ten critical components that may work together to form new opportunities for students. The first component is a STEM-focused (Science, Technology, Engineering, Mathematics) curriculum that includes strong courses in all four STEM areas, intentionally integrated into STEM and non-STEM subjects. The second component is that STEM-course instructional practices and strategies, grounded in research, focuses on project based learning. The third component requires the school's structure to have the chance to change the students' relationship between one another, teachers, and the acquisition of knowledge. The next component involves threaded into areas considered informal, such as clubs or apprenticeships. The remaining sequence by Peters-Burton et al. (2014) involves real world STEM partnerships, early college-level coursework, well-prepared professional growth, and supports for underrepresented students.

Conceptual Learning

The United States National Science Foundation, through a series of workshops, identified nine "Big Ideas" to be addressed when it comes to teaching about nanotechnology and nanoscience. These nine ideas include: size and scale, structure of matter, forces and interactions, quantum effects, size-dependent properties, self-assembly, tools and instrumentation, models and simulations, and science, technology, and society (Stavrou et al., 2015; Hingant & Albe, 2010). Aspects of these ideas can be introduced in early secondary education and expanded upon throughout middle school and high school in a systematic progression. Many proposed frameworks for nanoscience education have a framework based on a constructivist theory of education (Laszcz & Dalvi, 2023; Khamhaengpol et al., 2021; Vygotsky, 1978). Embedding the "Big Ideas" into middle school and early high school science and math courses helps prepare students for more specific nanotech and nanoscience concepts in later high school and college coursework.

Conceptually, one of the biggest challenges facing teachers and students with regards to nanotech education is simply the size and scale of the topic itself. Concepts of very large and very small objects are not easily understood by students (Hingant and Albe, 2010). Students have been shown to struggle with understanding the size and scale of objects without conceptual comparisons. Tretter et al. (2006b) demonstrated understanding regarding the size and scale of objects at the nano-level was highly inaccurate. Struggling to conceptualize extreme scales is a barrier to accessing nanotechnol concepts. Tretter et al. (2006a) found that twelfth-grade and doctoral students had a more refined size and scale knowledge than younger aged students and linked that knowledge to both direct and indirect experiences. It is essential for the future study of objects on the nanoscale to develop a learning progression within secondary math and science courses that enhance students' abilities to conceptualize minute objects by providing experiential learning. The use of tools and technology can further help with creating these indirect experiences since objects and interactions on a nanoscale cannot be directly observed (Hingant & Albe, 2010). Furthermore, students' understanding of size and scale has been shown to positively correlate with math and science abilities across these grade levels (Chesnutt et al., 2018).

With this understanding, Delgado et al. (2008) studied students in grades seven through eleven to determine a developmentally consistent learning progression for students. The authors studied four aspects of size and scale: ordering, grouping, relative size, and absolute size. These four aspects are logically connected so the consistency of the students were studied across these four aspects. The researchers found that, "these findings strongly suggest and are consistent with a developmental trajectory in which a learner first acquires consistency between ordering and grouping, followed by ordering and relative size, then ordering and absolute size, and finally absolute and relative size." (Delgado et al., 2008, p. 9). The study's results illustrated that in order to prepare students for education in nanotechnology, embedding size and scale concepts gradually throughout math and science courses in middle school and early high school would be beneficial. Taylor and Jones (as cited in Hingant & Albe, 2010) argued that students must have a critical level of proportional reasoning ability to understand the relationship between surface area and the volume of objects. This understanding reinforces the "Big Idea" of size-dependent properties. One of the important concepts in nanoscience is this very ratio that changes with the size of the object and is maximized at the nanolevel.

Proportional reasoning is an important mathematical concept introduced typically in early middle school grades. Ensuring students' understanding of ratios and proportions, while already an important part of math curricula, facilitates students making connections to these specific shapes and sizes.

Curricular Relations

Nanotechnology is related to and can be interwoven within several disciplines. Beginning in primary school, students can be afforded opportunities for exposure to nanosciences within courses provided throughout their educational experience. Nanotechnology and nanosciences are not limited to solely STEM disciplines and provide learning experiences beyond traditional STEM course offerings. (Figure 3).

Chemistry

Chemistry education primarily focuses on the properties and relationships of elements, molecules and compounds. The aforementioned aspects of chemistry fall into the realm of nanoscience, given the size of molecules and particles. Nanoscience involves altering the properties of molecules which affect the structure's bonding relationship between compounds (Lozano, 2022; Rafique et al., 2020; Taha et al., 2022).

Biology

Biology education focuses on the relationship between organisms and the natural world. Nanomolecules can provide certain organisms abilities to better their chances of survival and reproduction. Along with aiding the survival of species in the wild, nanotechnologies are also used in the field of medicine to better treat diseases and ailments (Cullinane et al., 2013; Doroudian et al., 2021; Ikumapayi et al., 2021).

Physics

Primary and secondary physics education deals in the structure of matter and its interactions in the universe. Topics of focus within this discipline involve structures on a nano or molecular level. Nanotechnology and nanosciences are utilized to alter the properties of materials through the alteration of a material's molecular structure (Rafique et al., 2020; Taha et al., 2022).

Engineering

Engineering is the practical employment of science in areas such as, but not limited to, design, architecture, machinery and infrastructure. Engineers are generally responsible for manipulating nanomaterials for industrial purposes. These materials can be utilized in sectors such as computer hardware, pharmaceutical materials, clothing. and food production (Hornyak et al., 2018; Mitman et al., 2008).

Computer Science

Computer science deals with computers, their hardware, programs, and algorithmic processes. Nanotechnology is utilized to advance computing speeds, processing power, and increasing computer memory storage (Ikumapayi et al., 2021). The creation of new computer technologies falls into the realms of both computer science and engineering.

Non-STEM

Nanotechnology is not only limited to the industries of science and engineering. Instances of non-STEM utilizations of nanotechnologies include clothing, food and cosmetics. Nanoparticles are harnessed to improve the quality of clothing or cosmetics by altering their original molecular structures, which in turn affects its external properties. In the food-production industry, nanotechnology can be applied to alter the taste of foods or its adhesion to surfaces (Lozano, 2022).

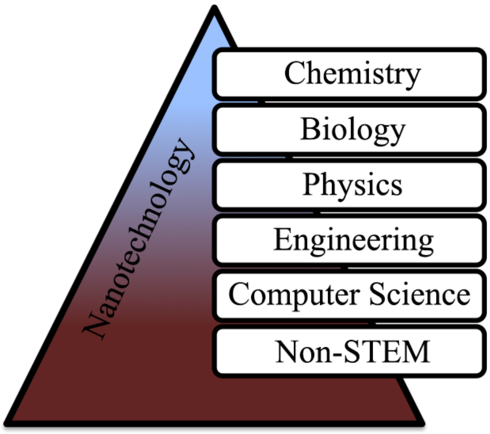

Figure 3. Relationships among nanotechnology and areas of study

Curricular Units and Connotations

It would be reasonable to assume there may be pushback from educators or administrators for nanotechnology implementation due to the perception of having to rearrange entire scientific curricula to include nanotech units. Fortunately, that may not be the case, as there are ways to add nanotechnology to already existing coursework. Nanotechnology possesses potential for inclusion in a number of course offerings, such as biology, chemistry and physics, as well as courses for non-science majors (Park, 2019; Quirola et al., 2018). For biology classes, nanotechnology can be interwoven into a unit covering the human immune system (Quirola et al., 2018). In the human immune system unit, topics concerning nanoparticle use in vaccines and medicines may be included.

Incorporating opportunities for student projects to include social interactions, debate, and teacher facilitation develops content knowledge as well as social skills development (Mandrikas et al., 2020; Quirola et al., 2018; Stavrou, et al., 2015; Vygotsky, 1978). A relatively simple experiment or demonstration includes providing biology students with an activity involving pouring water and then honey on a cabbage leaf. Students then observe how both substances form a ball on the surface of the cabbage leaf before rolling off (Cullinane et al., 2015). Students would then pour the water and honey on another leaf, to which they would compare and contrast their observations. This experiment can be used to introduce and interweave the concept of nanoparticles and their occurrence in the natural world (Cullinane et al., 2013; Quirola et al., 2018).

In chemistry it was suggested to include nanotechnology in a unit dedicated to polymers where the use of nanoparticles in manufacturing would be discussed. Quirola et al. (2018) recommended that students create models of nanoparticles and their bonds to better visualize their functionality. Blonder and Sakhnini (2017) also conducted a study in Israel where they were able to use their already existing high school chemistry curriculum and insert nanotechnology topics. The Israeli chemistry curriculum covered the following topics: basic concepts, atomic structure, structure and bonding, oxidation-reduction, acids and bases, the chemistry of foods, and kinetics. The curriculum also had optional units on polymers, physical chemistry, and biochemistry. Blonder and Sakhnini (2017) also noted that the curriculum generally follows worldwide chemistry progressions and thus, their study could be applied and replicated in other countries. Ha and Lajium (2022) had also found that teaching nanotechnologies in secondary chemistry classes and making real-world connections increased student motivation for learning.

Physics would seem to be the most ideal content area to interweave nanoparticles given the topic’s focus on molecular structures and intermolecular interactions. Quirola et al. (2018) recommended using physics to introduce the concept of the nanoscale and nanotechnologies. An activity that was utilized in the Quirola et al. study was the classification of items on the micro, macro, nano and subatomic scales. From there, the concept of surface-volume ratios would be taught, where the concept of nanoparticle manipulation could be made with real-world connections.

Extracurricular Opportunities

Nanoscience and nanotechnology concepts can be easily embedded within existing middle and high school STEM curricula. Exposure to these concepts, at the very least, helps to provide a baseline scientific literacy concerning nanotechnology and its implications in science and society (Hingant & Albe, 2010; Spyrtou et al., 2021). The goal is that nanotechnological concepts will inspire a number of students to strive to engage in deeper learning regarding nanoscience and nanotechnology. One potential avenue for middle and high school aged students, short of specific nanotechnology courses, would be through extracurricular opportunities. Peters-Burton et al. (2014) lists blended formal/informal learning beyond the school day and real-world STEM partnerships as two of their ten critical components of Inclusive STEM High Schools (ISHSs). Providing extracurricular opportunities such as clubs, camps, or short after school courses would be relatively easier than creating a whole new curriculum, adding instructors, or changing school schedules to address the potential needs of students wanting to expand their knowledge of nanotechnology prior to higher education.

Teacher Professional Growth

Nanotechnology is not a topic that is typically taught in teacher preparation programs. For schools to remedy this issue, in the short term, the implementation of nanotechnology into curricula requires professional growth opportunities for teachers. Teachers typically partake in professional growth for reasons such as advancing their careers, mandated requirements, or staying up-to-date with respect to pedagogy (Feldman-Maggor et al., 2022). In order for the successful implementation of nanotechnology in existing curricula, teachers must commit to engaging in professional growth. Effective professional growth garners higher success rates when growth is school-based, engaging, and able to be sustained for long periods of time to allow for cycles of reflection (Borko et al., 2010). Another option that may entice more STEM educators, which has become increasingly popular since the COVID-19 pandemic, is the ability to partake in professional growth opportunities in an online, virtual setting.

Building the Future: Higher Education

As students progress from primary education to secondary education, and finally higher education, courses and the course content itself becomes more and more compartmentalized. Students transition from elementary grade level content to precise, categorical department and course content in college. Given the more rigidly structured, categorized course assignments in education, promoting nanotech coursework or courses outside of science creates challenges for recruiting student nanotechnology course enrollment.

A strategy that has been employed for soliciting student enrollment in nanoscience aside from student science majors, is nanotechnology for non-science undergraduate majors (Park, 2019). Facilitating a non-science major enrollment option exposes a greater number of students to principles of basic chemistry, nanotechnology applications, and utilization of nanotech concepts for generating conceptualization. Employing a non-science major course offering provides yet another bridge for transitions from primary education to secondary education and finally higher education. The course included lab exercises, exams, and an applied project to assess students' understanding. The goal was to utilize chemistry for introducing relatable, conceptual nanotech applications for promoting critical thinking and integrative learning (Park, 2019).

Nanoscience Connections and Applications

Biological and Medical Science

Nanotechnology has aided in the role of creating significant strides in the field of medicine and pharmaceuticals. Nanotechnology has been shown to have a greater efficacy for treating patients, as the nanoparticles have been shown to specifically target areas of ailments (Doroudian et al., 2021; Ikumapayi et al., 2021; Lozano, 2022). With the success and continuous development of nanoparticles in the biological and biomedical fields, it is reasonable to predict a growing industry and job market (Figure 4).

Environmental Science

Climate change is an issue that is not new to many. The issue of climate change stems from human activities such as releasing carbon emissions into the atmosphere, through means of automobile emissions or pollutants released from factories. As a result, environmental scientists have been working to reverse and minimize the negative changes to our planet. Nanotechnologies are being employed in the field of environmental sciences to improve the areas of waste management, air pollution, and water scarcity (Taran et al., 2021).

Chemistry

University level chemistry is positioned to delve much deeper into the relationships of elements with respect to the real-world. Resources at the university level provide college students with a more hands-on, guided-inquiry approach to chemistry in comparison to what is available at the secondary educational level (Jesionkowska et al., 2020; Lati et al., 2019). Along with a deeper understanding of the scientific discipline, universities are better equipped to impart students with the necessary skills to find employment in their respective field as a result of required laboratory classes. Nanotechnologies are also applicable in the field of chemistry as a result of potential alterations to the bonds of chemicals and molecules, which in turn can improve the properties of the elements in comparison to their natural forms (Rafique et al., 2020).

Forensics

Forensics is a relatively newer field of science in comparison to its counterparts of biology, chemistry, and physics. The field of forensic science focuses on criminalistics and is relevant for matters pertaining to examining evidence concerning criminal law. The addition of nanotechnologies to forensic science has allowed for improved detection, recognition, and analysis of crime scene evidence (Tambo & Ablateye, 2020). Advancements in nanoscience may lead to an overall improvement of the legal system.

Physics

The study of physics typically delves into the interactions of all matter in the universe on an intermolecular level. As such, it can be considered the basic framework for all science and engineering disciplines. Given those intermolecular relationships and measures, nanoscience possesses the closest relationship with the field of physics. The close relationship of concepts, coupled with nanoscience's interdisciplinary nature, has led to the pioneering of concepts that have advanced technologies such as cancer treatment and microscopy (Bayda et al., 2019).

Engineering

To describe the field of engineering as vast and diverse would be an understatement. Just as there are a plethora of topics that fall under the umbrella of science, the same can be said for the discipline of engineering. Nanotechnology has allowed for substantial progress in a variety of engineering fields. For instance, nanotechnologies have been wielded by biomedical engineers to improve already existing CRISPR technologies to genetically engineer plants to better the production of therapeutics, biomaterials, and bioenergy (Demirer et al., 2021). Another stride made by nanoengineering is the improvement of transportation. Through the employment of nanoparticles, the strength, durability, and longevity of concrete and cement on highways has improved (Mobasser & Firoozi, 2016). The previously mentioned examples are just a few of the variety of uses of nanoparticles by engineers.

Material Sciences and Manufacturing

In addition to the use of nanomaterials for identifying solutions to some of the world's most basic needs, nanomaterials are being employed to improve everyday life. According to Talebian et al. (2021) nanomaterials are used in cosmetics, sports and fitness, textiles, and home appliances as well as in many other industries. Considerable investments in nanotechnology has led to the increased production of nanoproducts, particularly in the United States (Talebian et al., 2021). These consumer products are manufactured in a diverse array of industries. Additionally, investment in nanotechnology does not appear to be slowing and the authors note that "A strong global economic growth and job creation is expected to emerge and strengthen in the coming decades" (Talebian et al., 2021, p. 59).

Computer Science and Electronics

Ever since the advent of computers in the mid-twentieth century, technology has allowed for ever smaller processors and storage devices. In 1965, Gordon Moore coined "Moore's Law" that stated that the number of transistors on a computer chip doubles every two years allowing computer devices to shrink exponentially. However, this law is running into physical limitations (Taha et al., 2022). Transitioning to the use of nanomaterials helps to overcome the physical limitations of traditional silicon transistors. Although still in the early stages of development, advances in quantum computing are increasing the calculating speed and storage capacity of computers tremendously (Taha et al., 2022). Computer science is a growing and high demand career path, and the future of computing requires understanding of nanotechnology. Coincidentally, the advances of computer science, machine learning, and ever growing data sets, allow for even greater research into nanotechnology and nanoscience (Taha et al., 2022; Talebian et al., 2021).

Food and Agriculture

Nanoparticles have an ever increasing role in the livestock and agricultural industries. The use of nanoparticles in modern farming practices have helped the industry respond to global population growth by reducing crop and animal loss. Nanotechnology is starting to be employed in formulations, pesticides, fertilizers, and even sensors (Mittal et al., 2020). These innovative uses are being employed to make the industry more resilient and increase food security. However, these uses are relatively new and growth in this area of nanoscience is essential. Additionally, further study is needed to examine risks and long term effects on soil, water, and the natural environment as a result of additional use of nanoparticles.

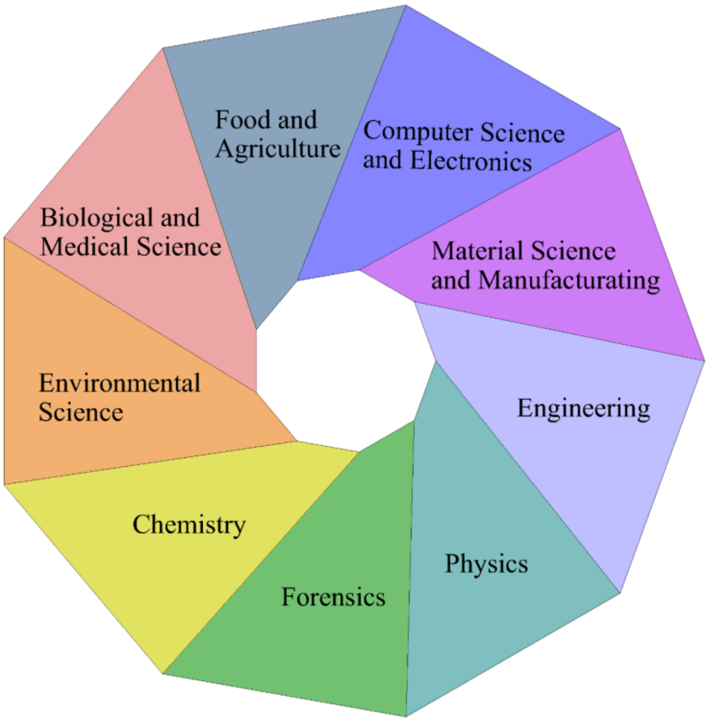

Figure 4. Nanoscience connections and applications

Conclusion

The field of nanotechnology, while dealing with incredibly small objects, looms large over the future of STEM education. As tools and technology increase our understanding of the very small, ironically, knowledge continues to grow. Interestingly, the properties of materials on a human level can change at the nanolevel with the changes in size, shape, inner, and outer geometric characteristics. Whether these nanoparticles occur naturally, or if they are artificially made, they afford a whole new world of possibilities across many different disciplines and industries.

Opportunities exist in medicine, environmental science, forensics, engineering, manufacturing, computer science, agriculture, biology, chemistry, and physics. Given the enormity of the financial, political, and societal potential, it is easy to identify how large investments in research and development are being made in nanotech by national governments, universities, non-profit organizations, and private companies. It is also easy to discern why addressing nanotechnology as a component of a STEM curriculum in education is relevant.

Students as early as primary school can begin learning to conceptualize and understand nano-measures using real-world examples and hands-on activities. Students in the middle and high school grades can begin to dive into the more abstract nanoscale objects and interactions not accessible to direct observation as they continue to develop abstract reasoning ability. Experiential, hands-on, inquiry-based activities can provide for a better conceptual understanding while also promoting social group interactions (Dignam, 2023; Kolb et al., 1984; Vygotsky, 1978).

Students at the primary school level can also begin to identify connections between science, technology, engineering, and society. Effective curricular design embeds and intertwines necessary learning progressions within current science and math courses from primary school through secondary school. To facilitate this process, high-quality and impactful teacher professional growth must be incorporated to close the gap between teacher knowledge and the curriculum. In addition, teacher pre-service programs afford knowledge for developing teachers to impart with future students. Finally, secondary schools can provide extracurricular programs for students to inspire learning more about nanotechnology in the forms of clubs, camps, and curricular offerings.

Students in higher education institutions are enrolled in courses that become more specialized and rigidly structured. Recruitment of students into nanotech fields is critical, as the need for this type of expertise is rapidly developing. Aside from science students, an introductory course in nanotechnology would help promote critical thinking as well as provide a background for those entering industries that will inevitably be influenced by nanotechnology. Nanotechnology is a rapidly expanding field with many applications across a great diverse set of industries. Educational institutions are tasked with preparing students with learning for jobs that do not yet exist. Possessing an awareness of current trends in areas of STEM and the labor market requires current academic studies in technology and education to be relevant for student preparedness.

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Virtual Laboratories in Science Lessons

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Introduction

Science is an important discipline that is intertwined with every aspect of our daily lives. For this reason, the science course, which ensures that the information learned can be applied in real life, is considered very important (Ergün, 2018). This course is considered to be a course in which students often have difficulty due to both the wide range of concepts it contains and the intensity of abstract subjects (Subaşı, 2012).

The information presented in lessons using traditional teaching methods causes students to memorize information (Biçer, 2011). However, using students' mental and physical abilities to perform activities related to the visible and invisible universe encourages permanent and meaningful learning (Çeken & Tezcan, 2006). Therefore, students should be offered effective learning opportunities by going beyond traditional teaching methods.

Laboratories are one of the places where science courses can be taught effectively and students' interest in the course can be attracted (Alkan et al., 1991). Laboratories allow science subjects to be associated with the real world and abstract concepts to be made more understandable (Fidan, 2018). The use of laboratories in science lessons not only increases students' interest in the lessons, but also has a positive effect on reducing conceptual misconceptions (Koç-Ünal, 2019). Along with these contributions, problems are sometimes encountered in the use of laboratories. These problems can be listed as missing or insufficient laboratory materials, the number of students in the classrooms being too high, teachers seeing the use of laboratories as unnecessary, and the experiments being only on display (Bilir, 2019).

The rapid advancement of technology has led to major transformations in many fields, including education. In today's "information age", the use of technology has become an inevitable necessity. The science course also has a strong relationship with technology. The Science Curriculum emphasizes the integration of the content taught with technology in order to provide students with perspectives appropriate to the needs of the age (Ministry of National Education [MoNE], 2018). This is because the use of technology in science courses provides students with creative thinking skills and increases time efficiency in the course, enabling faster achievement of course objectives (Koç-Şenol, 2012). This situation reveals the importance of virtual laboratory applications.

For this purpose, this section will provide information about laboratory and virtual laboratory applications within the scope of science course.

Using Laboratory and Technology in Science Lessons

Science is a subject that allows students to discover what happens in nature through experiments and observations. Science topics are often complex and involve abstract concepts. In order for students, especially at the primary school level, to understand these abstract topics, concrete materials should be used (Çepni & Ayvacı, 2016). For this reason, laboratory environments are considered the cornerstone of science education (Hofstein & Lunetta, 2007).

Laboratories are one of the most important learning environments where students can observe events in nature, make sense of the scientific method and develop their field-specific skills (İlhan, 2013). In general, laboratories, which are defined as well-equipped environments where observations are made while performing experiments, are an important part of science (Anılan, 2016). As a matter of fact, it is known that laboratories, which are the key to scientific progress, provide students with many positive characteristics. Laboratory practices provide students with a unique learning space where they can collaborate and work in small groups to examine scientific hypotheses (Hofstein & Lunetta, 2004). It also stimulates students' curiosity and contributes to the development of problem solving, idea generation and creative thinking skills (Yenice, 2005). In addition, it increases students' reasoning skills and provides them with the opportunity to understand scientific knowledge (Yılmaz, 2017). Laboratory practices during science teaching help students to concretize abstract concepts (Baltürk, 2006). Many studies emphasize that meaningful learning of science courses depends on the presence of a science laboratory (Hofstein & Lunetta, 2004; Hofstein & Mamlok-Naaman, 2007; Tobin, 1990).

Batır (2018) summarized the purposes of using laboratories in science courses as follows: Laboratories aim to better explain the content to students with visual materials to make abstract concepts concrete. At the same time, it increases students' motivation for the science course. By providing students with the experience of learning by doing and experimenting, it contributes to the development of a positive attitude towards nature, living things and the environment. It helps students understand the subjects better by ensuring that the theoretical knowledge is associated with daily life through experiments conducted in the lessons. It also increases students' self-confidence and encourages their interest in science and scientific knowledge by applying the working principles of scientists. Topsakal (2005) stated that the use of laboratories in science courses aims to develop students' mental abilities to gain a scientific approach; to become science literate who can question unknown questions, investigate, observe and interpret the results instead of only answering known questions.

In addition to these benefits of laboratory practices, it is known that some difficulties and problems are encountered while performing laboratory practices. For example, when the class size is high, it may be difficult to perform laboratory applications effectively. In addition, experiments that should be done individually may be done in groups or as demonstrations or even not done at all. The high cost of laboratory materials may cause inadequate equipment. At the same time, the coexistence of many chemicals may cause safety problems and the lack of laboratories in some schools may constitute obstacles to qualified laboratory practices (Anılan, 2016; Günlü, 2019).

Therefore, the use of technology in science laboratories can help solve these problems by providing students with the opportunity to perform costly, dangerous or highly complex experiments outside the laboratory.

Today, technological developments have led to radical changes in many areas from business to education, from health services to communication. The role of technology, which is an integral part of daily life, especially in the field of education, is becoming more and more important every day. It is inevitable to integrate technology into education in order to carry out a qualified education and training process and to train students competently (Barut, 2015). When the literature is examined, it is seen that the use of technology in education has many benefits. The first of these is that it improves the quality of the learning process. Technology provides students with a more effective and interactive learning experience, allowing them to penetrate knowledge more deeply. In addition, technology saves time for teachers and students. Teachers can convey information to students more quickly and effectively and increase learning time. Another important contribution of technology in education is to maintain the quality of education while reducing costs. It can offer a more economical learning experience than traditional education methods. Finally, technology makes students more active in the learning environment. Interactive educational tools and resources provide students with more participation and contribution to learning (Akkoyunlu, 1998). In parallel with these benefits, İşman (2005) listed the advantages of using technology in education as follows:

- The use of educational technology gives both students and teachers more freedom in terms of time and space. It offers a more flexible learning experience compared to traditional teaching methods.

- In traditional teaching, information usually comes from second- or third-hand sources, whereas with educational technologies, information can be obtained directly from first-hand sources.
- Educational technology has enhanced and enriched education and has the potential to provide equal educational opportunities to people in every corner of the country and even around the world.
- By using educational technologies, teachers can create learning environments that match students' abilities. This supports each student to learn at their own pace.
- Educational technology improves students' productivity and accelerates the pace of learning by developing new learning environments and methods.
- The use of educational technologies offers students and teachers multiple and diverse teaching and learning options.
- Educational technologies offer students the opportunity to maintain continuous learning throughout their lives.

The use of technological tools in science education and their integration into educational processes are of great importance in ensuring effective and continuous learning. With the use of technology in science education, students have easier and faster access to science activities. Technology makes it easier to record findings, consolidate experiences, and transform ideas, observations and concepts into results and process reports more easily. It also contributes to improved teaching and learning communication. Finally, it enables the creation of a broad learning community through the Internet (Bell & Fenton, 2006).

Technology is now widely used in science laboratories as well as traditional classrooms (Chiu et al., 2015). The use of technology in science laboratories provides an important advantage by giving students the opportunity to try costly, dangerous or complex experiments outside the laboratory. The literature shows that the use of technology has positive results in science laboratories (Olympiou et al., 2013; Trundle & Bell, 2010). Technological materials are widely used in learning environments, especially in science education. These materials include various instructional technologies such as simulations, augmented reality applications, digital storytelling, 3D printing technology, digital games, QR codes, social media-based learning, and mobile applications (Johnson et al., 2015).

Using Virtual Laboratory in Science Course

Virtual Laboratory

With the changes brought about by the 21st century, the concept of "virtual laboratory", which combines experiments with scientific process skills, has been developed in order to improve students' scientific thinking skills (Dana et al., 2001; Bruder, 1993; Keller & Keller, 2005). There are many definitions of this concept in the literature. Virtual laboratories are learning tools that allow students to reinforce their theoretical knowledge with hands-on experiments and provide a virtual simulation of physical laboratory experiments (GroB, 2002). These laboratories are a type of technology that simulates a real laboratory using three-dimensional visuals and animations created with computer-based technologies, allowing users to interact with objects in this environment (Tatlı & Ayas, 2011). Prieto-Blâzquez et al. (2009) defined virtual laboratories as virtual learning spaces that can be customized in accordance with student and teacher needs and used for conducting experiments.

Two- or three-dimensional technologies are used to create virtual laboratories. With this method, the real laboratory environment can be modeled virtually. In this way, students have the opportunity to perform experiments that can be performed a limited number of times in traditional laboratories. Students gain experience by interactively using virtual equipment using tools such as keyboards or hand controllers. These experiences can be presented through desktop or laptop computers using two-dimensional technologies or through augmented reality glasses using three-dimensional technologies (Cummings & Bailenson, 2016). The virtual laboratory is modeled with software tools such as Java, Flash, XML and LabVIEW (Chen et al., 2010).

Advantages of Virtual Laboratory Applications

Virtual laboratories are one of the technological innovations that represent a significant shift in education and research in science and other laboratory-based disciplines. They are tools that bring some or all of the traditional physical laboratory experiments to online and simulation-based platforms. This approach has a number of important advantages. First of all, the use of these laboratories is highly economically advantageous. They require a much lower budget than traditional laboratories (Abulrub et al., 2011). In addition, science experiments that students find difficult to observe directly, such as some chemical reactions, radiology, electricity and thermodynamics, can be examined in detail through virtual laboratories (Çavaş et al., 2021).

Virtual laboratories also provide access to students at any time, eliminating space and time constraints (Abulrub et al., 2011). Through simulations, students can investigate science topics in depth and access important information about the results of experiments. These laboratories provide students with the opportunity to change variables in experiments, adjust the speed of the experiment and perform experiments repeatedly. This encourages students to actively participate in the experimental process (Moshell & Hughes, 2002)

Virtual laboratories can also be adapted for students with special needs, which provides equal opportunities (Wang et. al., 2009). In addition, these laboratories provide the opportunity to perform dangerous experiments safely (Abulrub et al., 2011). Finally, students who gain experience in virtual laboratories are better prepared for the problems they may encounter in real laboratories. Therefore, virtual laboratories play an important role in science education (Çavaş et al., 2021).

Disadvantages of Virtual Laboratory Applications

Virtual laboratories offer great opportunities in science and other laboratory-based disciplines, but they also bring some disadvantages. These digital tools, which are used as an alternative to traditional physical laboratory experiments, have some limitations and challenges. Çavaş et al. (2021) expressed these limitations and challenges as follows:

Students may feel that virtual experiments do not have the same impact as real-world experiments. In addition, the use of virtual laboratories can be a challenge for students who do not have internet access, computers or tablet computers. Preparing educational materials and creating simulations of virtual experiments may require time and effort. In addition, inadequate or poor-quality design of virtual laboratories may cause attention deficit in students. Finally, virtual laboratories cannot offer students sensory experiences such as smelling, touching and feeling (Çavaş et al., 2021).

While some studies support the view that virtual laboratories are less costly than traditional physical laboratories, some studies suggest that virtual laboratory setup can be more costly (Şardağ & Tüysüz, 2020). In addition, older teachers with professional seniority may be less enthusiastic about new educational methods. This may cause them to have difficulty in adopting virtual laboratories and show resistance to these practices (Velev & Zlateva, 2017).

Virtual Laboratory Applications Used in Science Teaching

Stellarium: It is a publicly available, education-oriented three-dimensional software. With this software, different features in the sky can be explored in detail and the sky can be observed live.

Accessed from: https://stellarium.org/

Figure 1. Stellarium software (URL-1)

Celestia: This laboratory contains many celestial objects such as the solar system, the Milky Way galaxy and thousands of stars. This software allows you to navigate the Solar System at any time and at any speed, giving you the opportunity to observe with spacecraft.

Accessed from: https://celestia.space/

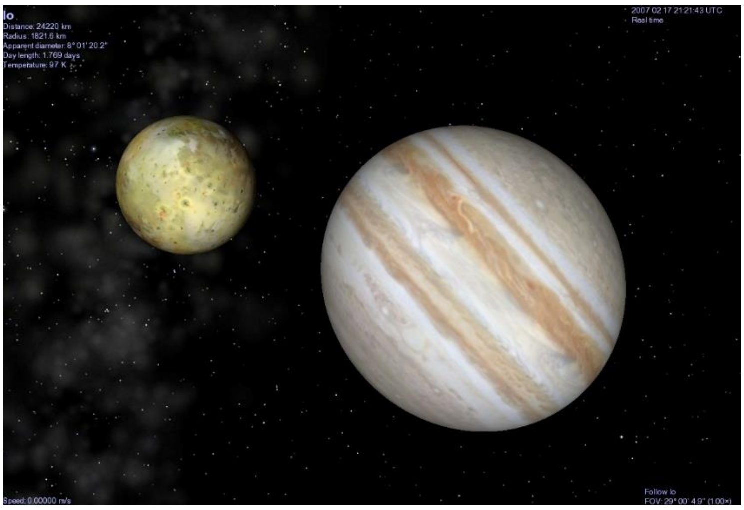

Figure 2. Celestia software (URL-2)

Yenka: With this software, science experiments can be carried out and math-based models can be created.

Accessed from: https://yenka.com/

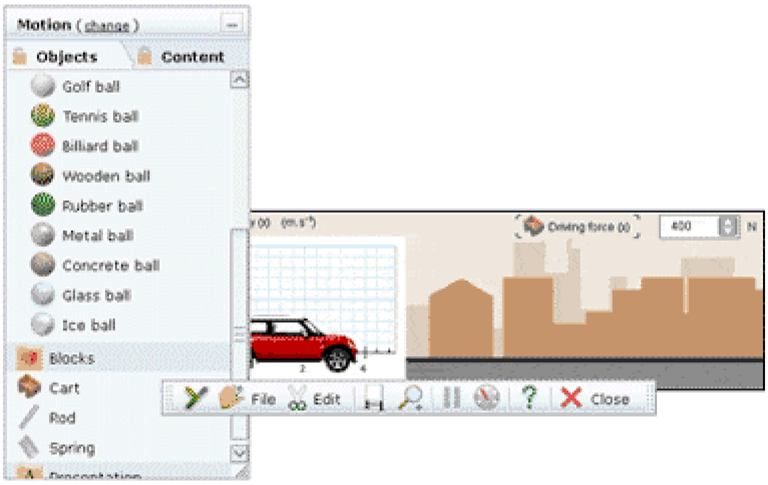

Figure 3. Yenka software (URL-3)

Phet Colarado: This virtual laboratory offers the opportunity to explore science topics interactively.

Accessed from: https://phet.colorado.edu/

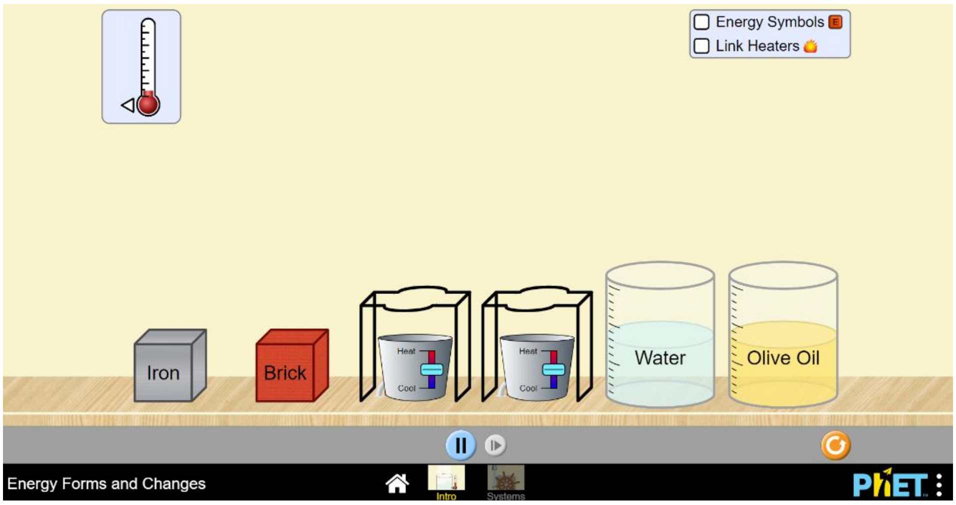

Figure 4. Phet Colarado software (URL-4)

Virtual Labs: This project includes more than 100 virtual laboratories and more than 700 web-based experiments developed for remote operation and viewing.

Accessed from: https://www.vlab.co.in/

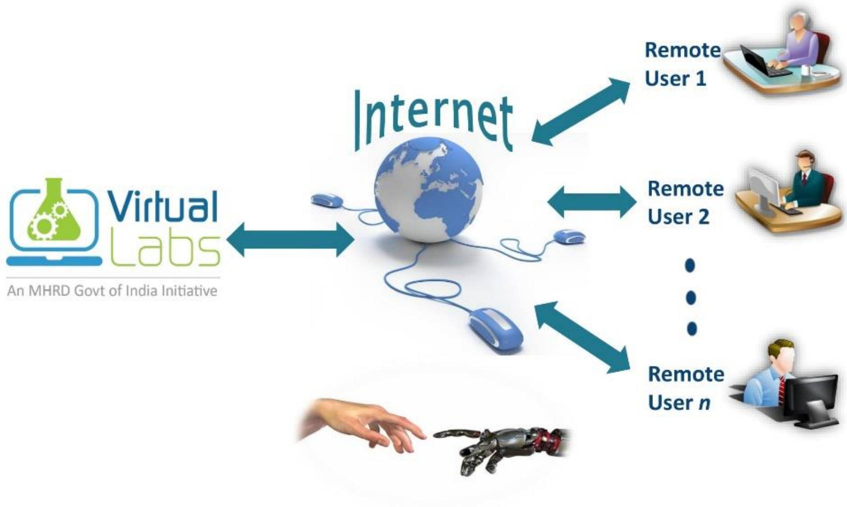

Figure 5. Virtual labs software (URL-5)

PrimalPictures: It is an online lab that presents human anatomy in three dimensions with real body scans and imaging data.

Accessed from: https://primalpictures.com/

Figure 6. PrimalPictures software (URL-6)

Go-Lab: This simulator supports the use of learning technologies in online laboratories.

Accessed from: https://chemcollective.org/

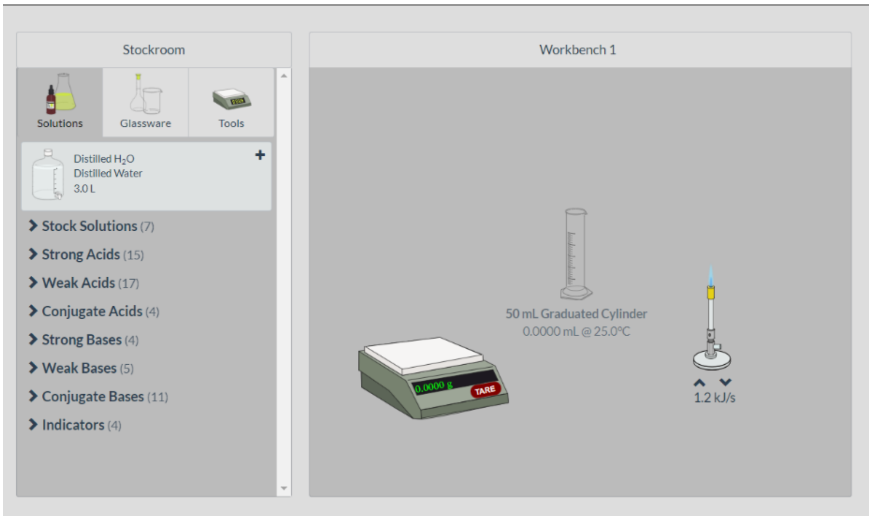

Figure 8. ChemCollective software (URL-8)

Conclusion

Laboratories offer students the opportunity to concretize science, develop scientific skills, test hypotheses, collaborate and think creatively. However, laboratory practices also have some challenges. These challenges include inadequate equipment, high costs and safety issues. Technology can help overcome these challenges in science laboratories. Indeed, technology can make science education more accessible, safe and affordable. Virtual laboratories are one of these technologies. The advantages of virtual laboratories include low cost, accessibility at any time, customization according to student needs, and security. However, there are also some disadvantages. These include; not creating the same effect as real-world experiments, access problems, lack of attention and lack of sensory experience.

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The Aesthetics of Experimentation: Conceptualizing and Actualizing a STEAM Program

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Introduction

Teaching and leading is both an art and a science. High-performing teachers and leaders educate to enrich the minds of educational communities while simultaneously lifting each spirit to inspire actualization. The blending of both disparate yet interrelated content areas such as Science, Technology, Engineering, Art, and Mathematics (STEAM) provides opportunities for teachers, leaders, and students to engage in blended leading, teaching, and learning for elevating both spirit and mind. STEAM is an interdisciplinary and transdisciplinary philosophical approach for providing meaningful cognitive and social supports in the acquisition of knowledge for learners (Bertrand & Namukasa, 2020; Colucci-Gray et al., 2019; Dignam, 2023; Küçükgençay & Peker, 2023).

The present chapter examines and explores qualities, systems, and processes of developing and implementing a school wide STEAM program. The author is a former secondary school science teacher, instructional coach, assistant principal, principal, and school district superintendent. While the author began his career teaching high school science for the better part of a decade, his latter two decades of experiences as an instructional, educational leader led to his current work as a professor of interdisciplinary leadership and educational administrative leadership in the United States. The author also possesses authentic experiences in developing and implementing STEAM course offerings and programs ranging from those in a large high school in an urban setting to a neighborhood high school in a suburban setting, as well as a small therapeutic school for students with special needs.

The Science of Art

Teaching and leading is both a science and an art. When we teach and lead we do so scientifically, and equipped with knowledge and facts concerning pedagogy, methodology, and theoretical constructs. Moreover, the social, emotional well being of students are brushstrokes of art that must be considered first, as students construct knowledge as a result of experiences and through social networks that promote connections for cognition (Kolb, et al., 1984; Vygotsky, 1978). When students are provided STEAM programmatic offerings, they are afforded opportunities to engage in experiential, constructivist learning, which is foundational for fostering social capital. The cultivation of social skills, collaborative learning, and constructivism presents students with avenues for enhancing conceptual understanding (Dewey, 1933; Piaget, 1972; Vygotsky, 1978).

A key approach to implementing any program is to embrace and put into practice both servant leadership and distributive leadership. Servant leadership naturally places the needs of others first, and by doing so, leaders are distinguished by serving the communities they lead (Blanchard & Broadwell, 2021; Greenleaf, 1998). Employing servant leadership also creates a sense of trust by the communities being served, which results in innovative behaviors and innovation within an organization (Khan et al., 2021). In addition, the utilization of distributive leadership provides school community members opportunities to be involved in decision-making, leading to a collaborative school culture and teacher job satisfaction linked to organizational goals (Jakobsen et al., 2023; Torres, 2019). When leaders provide opportunities to share leadership, the act of distributing leadership positively impacts students. Furthermore, teacher-student relationships improve as a result of teachers taking ownership of endeavors and recognizing the whole student and each student's personalized needs (Kallio & Halverson, 2020). The following passages provide a historical narrative analysis in both objective and first-person perspective regarding the forging of partnerships for supporting STEAM programmatic development, implementation, and sustenance.

A Canvas for Innovative Design

Coaching, Teaching, and Leading

After nearly ten years as a high school science teacher, the author transitioned from his role as a high school biology instructor to an area district-office instructional coach for high school science (primarily biology, chemistry, and physics). The position was valuable in terms of providing opportunities to develop administrative capacity, as the post required curricular supports and professional growth opportunities for teachers within a portfolio of 23 diverse high schools. Each school was unique in terms of community, culture, climate, instructional capacity, and school-based leadership. As an instructional coach, the author served high schools primarily located in Chicago's Englewood community. Schools within the area included neighborhood high schools, such as Englewood, Robeson, Harper, Tilden, Kennedy, etc. as well as York High School in Cook County Prison. District area office instructional coaching experiences afforded opportunities to evaluate and improve science curricula, assess opportunities for providing collegial coaching, and to support teachers with professional growth opportunities to improve professional capacity. The author was also able to work directly with each school's principal and administration to further develop perspective in terms of culture and climate, leadership style, and resulting leadership impact on the learning organization.

Professional Erudition

Teachers are better equipped to enhance student learning through engagement in professional growth (Kirner & Lebrun-Griffin, 2013). Typically, teachers receive professional growth through professional development, often involving attending a variety of workshops or presentations with a general focus. In contrast, site-based professional development distinguishes itself from traditional professional development by involving specific individuals with a defined purpose (Strike et al., 2019). Moreover, professional learning specifically targets skills to foster ongoing professional growth and is regularly revisited. During the author's tenure as a principal and superintendent, he developed and established a training service he refers to as *professional erudition*. Professional erudition combines elements of site-based professional development *and* professional learning, featuring *targeted* periodic development *and continuous*, preplanned learning with ongoing supports. Professional erudition is thematic and personalized, emphasizing both whole-group, targeted learning and individualized scholarship. The author continues utilizing professional erudition with instructing graduate and postgraduate higher-education students and professional erudition practices implemented during leadership roles in school and district communities. The term "professional erudition" is consistently referenced throughout the chapter.

External Partnership-Building

While serving a variety of schools and providing instructional leadership supports, the author established relationships and partnerships with universities for providing an array of district level supports for schools and their local communities. Those professional experiences provided invaluable leadership learning and practices for working with a variety of stakeholders for developing partnerships. Engaging diverse communities and creating an inclusive STEM (Science, Technology, Engineering, and Mathematics) program provides expanded opportunities, preparation for advanced STEM studies, early college-level coursework, and supports for underrepresented students (Peters-Burton et al., 2013). Supports for all learners while engaged in STEM learning has also been found to impart the development of perseverance and transferable skills as life skills in students (Bertrand & Namukasa, 2020).

An Artist's Palette in a Scientist's Laboratory

The author began his career in Chicago's North Austin community before later transferring to the north side of the city and then serving as an area district-office instructional coach. Those experiences provided opportunities to refine and employ science-based instructional leadership for teachers and administrators with an emphasis on affording students relational, experiential, project-based learning for active learning (Kolb, 1984; MacDonald et al., 2020). Those particular efforts took place prior to the acronyms STEM or STEAM originating or becoming commonplace in education. However, employing an artistic approach for blended science, technology, engineering, and mathematics learning was employed for engaging all learners (MacDonald et al., 2020). When active learning for learners of all backgrounds is provided through inclusion of the arts in STEM, the experience of learning is highly engaging for students (Bertrand & Namukasa, 2020; Jesionkowska et al., 2020).

After serving as an instructional coach for the sciences, the author was offered a position as an assistant principal on Chicago's north side of the city. That particular school, Lane Technical College Preparatory High School, is the school the remainder of the current chapter will discuss related to conceptualization and actualization of STEAM programming. Lane Technical College Preparatory High School is one of the largest high schools in the United States with approximately 4,500 students and 250 staff. The size of the school and campus is much more akin to a small college than a high school and possesses students of every socio-economic, racial, national, religious, and oriented background. The author was charged with overseeing curricular programs, scholarly programming, reinvigorating the school's science program, and serving as the school's curriculum director and Advanced Placement coordinator.

The previous coaching experiences in working with two-dozen diverse school communities and actively establishing and nurturing external stakeholder and university partnerships proved to be extremely useful in spearheading new STEAM course offerings. As teams developed and launched new courses, such as *Engineering Design, Principles of Engineering, Neuroscience, Art in Mathematics*, etc., they were able to expand innovative course offerings and increase the number of STEAM instructors. There was a very high demand for the dozen-plus new course offerings, which resulted in the science and art departments nearly doubling in size to deliver a supportive, transdisciplinary and interdisciplinary philosophically-based STEAM program (Bertrand & Namukasa, 2020; Colucci-Gray et al., 2019). STEAM approaches, such as the program deployed, significantly enhance students' grasp of both scientific and artistic concepts, while fostering a greater sense of preparedness and promoting individual responsibility and cooperative interaction (Bassachs et al., 2020).

The author also led the development and establishment of a transdisciplinary and interdisciplinary, cross-curricular program called Alpha-STEM for students specifically interested in research. The Alpha-STEM program consisted of groups of 28 students each for attending STEAM courses as a cohort for a four-year course sequence. Teachers assigned to the cohort collaborated as colleagues in constructing and delivering cross-curricular team lessons for authentic transdisciplinary, interdisciplinary teaching and learning.

During the first year of Alpha-STEM, the school was able to recruit 56 students for two cohorts. Within five years, Alpha-STEM grew to approximately 670 students in over 24 cohorts at four grade levels (Figure 1). Employing a cohort model is advantageous, as it enables students to identify connections across disciplines for improved relations, team-led learning, and self-reflection (Bassachs et al., 2020). Furthermore, critical reflection assists students in cultivating strategic competences, skills, attitudes, and emotions related to their future actions, while also aiding in the development of critical social skills for communal learning (Bassachs et al., 2020; MacDonald et al., 2020).

Figure 1. Students on campus

Science Olympiad and Robotics

Innovative Visions for Learning

Active collaboration with the school's science department chair as well as partnering with two newly hired physics teachers resulted in the establishment of Science Olympiad and robotics for students. Science Olympiad is a program that helps students develop abilities in STEM through challenging problems and social and life skills development. (Kulbago et al., 2016; Oliver & Venville, 2011). Science

Olympiad also provides opportunities for students to explore new disciplines, build community, and prepare for future STEM careers (Kulbago et al., 2016).

Participation in the Science Olympiad strengthens students' resolve to pursue STEM-related careers and refine twenty-first century skills through engagement in competition (Sahin et al., 2015). The administrative-physics teacher partnership formed resulted in the creation of Science Olympiad and robotics course offerings rather than simply presenting after school, extracurricular clubs. While being in a position to offer Science Olympiad and robotics as clubs or extracurricular activities was an exciting prospect, the partnership resulted in a like-minded administrative-teacher team for creating actual Science Olympiad and robotics courses for course credit.

Administrative efforts entailed reviewing costs, needs, and demands for implementing robotics as a course for students to earn physics credit. Time was devoted to exploring curricular units and material needs and space within the building to house the establishment of a robotics lab. Collaborative efforts included fundraising with parents, community, and alumni, as a three-year plan was devised with startup costs for creating a sustainable robotics program. After two years of development, the school began advertising robotics as a new course offering.

The team was open to exploring all creative curricular and facility possibilities for establishing a dynamic robotics program. Those efforts included researching a Verizon VGo Robot for use within STEAM program offerings and for supporting homebound students with serious illnesses to take part in classes (this was many years prior to the Covid-19 pandemic). Science Olympiad provides students with out-of-school STEM activities and exposes learners to a variety of new disciplines for piquing student interests. Engaging out-of-school homebound students also provides continued participation and connections to STEM (Smith et al., 2021). Science Olympiad supports students socially by providing a unique environment where students feel included, safe, and surrounded by like-minded individuals (Oliver & Venville, 2011). These meaningful attributes paved the way for establishing a creative, cutting edge program for students of all backgrounds to design and construct knowledge. Students partnered with outside organizations and battled in robotics competitions for fun as well as for testing robotics builds.

Robotics was designed to expose students to the branch of technology that deals with the design, construction, operation, and application of advanced, industrial grade robotic mechanisms. Students also engage in programming, which can be employed as early as early childhood education through the use of programmable toys and educational kits that helps children develop initial programming concepts in a developmentally appropriate and supportive learning environment (Hillmayr et al., 2020). Robotics provides students with the opportunity to use professional computer programming environments, 3D design software and industrial grade hardware to devise, program and build sophisticated robots for developing problem-solving skills, critical thinking abilities, and creativity (Arlegui et al., 2008). Students specialized in teams such as programming, drivetrain, pneumatics and electronics, and then, collectively, to create robots seen everywhere from science fiction to medicine, animatronics, and industry. Robotics promotes interest and scientific curiosity, as well as social skills through teamwork (Arís & Orcos, 2019; Arlegui et al., 2008). The curriculum developed was fun, exciting, and challenging for the entire school community. Rather than focusing on a linear progression of information (as in a traditional classes), robotics was project-based with students being experientially immersed for contextual, meaningful learning. Experiences included successfully programming digital and analog controller systems and I/0 units such the cRIO and RobotRIO using Java programming language, utilizing both vector and matrix math to inform programming decisions and strategies, employ calculations/measurements to determine the appropriate size or strength of industrial grade components working together in a system, and efficiently completing tasks.

Developing and implementing STEAM required administrative dedication and support. Educational leaders actively support robotics and the development of scientific inquiry and literacy skills through constructivism by ensuring professional erudition, allocating resources to enhance STEM education, and encouraging participation in academic competitions (Dignam, 2023; Swanson et al., 2021).

Affording students robotics as a course and budgeting to construct a large robotics research lab resulted in the creation of an environment for supporting the spirit and minds of each learner. In addition, robotics II was added as an upper-level course for students who successfully completed robotics I, as well as a course called adaptive robotics for students with special needs to provide multiple pathways of participation in robotics.

Six Guiding Principles

The author was named principal of the school and established a requirement for all new course proposals that served as a guiding principle for future course offerings leading to implementation. The *Six Guiding Principles* were grounded in distributive leadership and required that all course proposal approvals must provide for (1) inclusion of special needs students (for example, in the case of robotics, an eventual adaptive robotics course), (2) a "social change" mandate that course designs, recruitment, and implementation efforts ensure female and diverse student representation, (3) innovative, creative courses include a commitment to professional erudition for supporting annual course cycle review, (4) a commitment for innovative learning space evaluation (visiting other schools, organizations, professional associations, etc.), (5) considerations, whenever feasible or possible, for middle school students to participate in innovative course offerings (the high school also housed a middle school academic center), and (6) active collaboration among transdisciplinary and interdisciplinary planning teams take place with the goal of creating functional cross-curricular course offerings for approved courses.

In addition to creating multiple levels of robotics and adaptive robotics, the robotics research lab provided supportive, active instruction and hands-on construction and testing of robots students built. In addition, the school's Science Olympiad teacher and one of his students were invited to the White House's annual STEM Fair and robotics students began to actively build in the new robotics laboratory and compete in the FIRST International Robotics Competition (Figure 2).

Figure 2. Robotics laboratory

Aquaponics

Watercolors and Pipettes

Aquaponics provides hands-on, experiential learning by providing a rich environment in which students interact with aquatic and terrestrial growth systems for observing how a variety of organisms work together to produce life-sustaining products (Bice et al., 2020; Kolb et al., 1984). Aquaponics utilizes a structural, closed-water-loop for breeding and nurturing fish (tilapia were the chosen species) and plants. Tilapia in the closed-loop system supply fertilizer for the plants and the plants, in turn, utilize the tilapia fertilizer for their own growth. The water nourishing the plants is constantly cycled back to the tilapia as a natural, filtered sequence for the tilapia with the loop continually flowing. Aquaponics is also transdisciplinary and interdisciplinary, as it integrates concepts from various fields such as science, health education, and technology and affords students with authentic hands-on scientific inquiry and scientific literacy experiences (Bice et al., 2020). Aquaponics supports STEM education by providing a real-world context for teaching science, technology, engineering, and mathematics concepts, as well as promoting problem-based learning, inquiry, design-based learning, and collaboration for facilitating understanding with respect to urban farming and sustaining natural resources for twenty-first century learning (Baykir et al., 2023).

Within the school, there were eleven enormous, empty classrooms that were approximately 4,000 square feet (some were significantly larger and afforded over 7,000 square feet of classroom space) going unused. The classroom spaces used to house shop classes first introduced in the 1930s but by the early 2000s they were either filled to the brim with garbage or being used as storage or makeshift office space (most shop classes were phased out of the school beginning in 1999). There was no strategic plan on campus for repurposing the spaces, which provided an opportunity for creating and establishing a strategic plan for revitalizing tech programming and implementing STEAM-based, innovative learning spaces and curricula (Figure 3).

Figure 3. Learning environments prior to renovation and construction

An abandoned classroom that served as a machine shop for 70 years was chosen for housing the aquaponics facility. The school team engaged an external vendor for facilitating the design of the aquaponics lab. The vendor happened to be working with a local university on another aquaponics lab space, which provided an opportunity to work with an external stakeholder as well as learn the blueprint process for a university-level, aquaponics facility in a high school setting. External partnerships served as resources in providing additional insight with respect to urban agriculture, which became part of the curricular design, and for articulation with college level course content in mind. The team also worked on designing a curriculum that was inclusive for all learners. Efforts were made to confer with special education to ensure aquaponics lab tables and beds were spaced appropriately for ease of access. The spacing between each bed also provided flow for all students while working in the lab (Figure 4).

The sheer size of the space afforded the aquaponics facility to function as a multiuse space, allowing classes to work on one side of the room while another section of aquaponics conducted lab work. Materials and manipulatives for use with a variety of other content areas were also accessible in the aquaponics facility. Courses such as art, mathematics, and economics took place in the facility to work and engage in interdisciplinary learning in an authentic, multiuse space. Art classes such as photography and drawing engaged in class assignments while mathematics courses recorded measurements with Vernier probes for use with calculators for solving authentic mathematics problems. Special education courses conducted classes or teamed up with other aquaponics classes for adaptive learning.

Students in the school’s autistic program worked with manipulatives such as vermiculite or lava rocks to facilitate hands-on learning for the development of scientific inquiry and scientific literacy skills development. In addition, students in the middle school academic center also utilized the space for biology content and scientific research. Aquaponics curricular experiences enhance social skills development through the promotion of student engagement and interactions for imagining and constructing knowledge (Thompson et al., 2023).

Figure 4. Aquaponics facility

Computer Science and Makers Innovation Lab

The Body Electric

Endeavors were undertaken to visit a variety of schools and institutions that were offering various forms of "makers" clubs, extracurricular activities, or had created makers workstations within their schools. Makerspaces have been shown to foster creativity by providing opportunities for learners of all ages to engage in hands-on innovative and creative activities. In addition, research studies have illustrated that makerspaces rank the highest in fostering creativity and innovation (Novak, 2019). While the trend was to place small makerspaces in a library or as a workstation with a 3D printer in a classroom, the goal was to establish a true makers innovation lab, and there was ample preexisting, unused space within the building. There were no interests in following trends. The author's goal was to elevate the school to move beyond trends and for other schools to follow or compete with Lane Tech, rather than Lane Tech following or competing with what others were doing. Creating STEAM hubs throughout the school was a priority goal in the author's capacity as an instructional leader.

During this same time, the school's computer science program was shut down and discontinued due to low enrollment and antiquated curricular offerings. Computer science curricular offerings were severely archaic and consisted of students merely taking one semester of Word and a second semester of Excel for computer science (CS) credit. Students demonstrated frustration with both the lack of curricular relevance and lack of rigor. Consequently, aside from Advanced Placement computer science, the electives offered were irrelevant and non-sustainable in terms of student enrollment and applicability. There was a concerted effort to revitalize a CS program dedicated to transdisciplinary and interdisciplinary STEAM learning for computational thinking. Computational Thinking is a problem-solving approach that involves breaking down problems into steps that can be executed through computer use. Computational Thinking is a way of thinking that connects CS with other subjects and is used for investigating and solving problems in STEM and STEAM fields (Lee et al., 2020). Computational thinking helps students develop problem-solving skills and the ability to formulate solutions, and is related to art as it can enhance creativity, design thinking and problem-solving skills in the context of digital design and visual arts, which supported the school's vision (Settle, 2012).

The team spent a full year re-visioning computer science course offerings and creating a foundation for ensuring future course offerings would remain relevant and sustainable. The team worked on developing and creating new, exciting, cutting edge computer science course offerings. Partnerships were forged with internal and external stakeholders to develop curriculum and recruit new staff to support students. In addition, there was a desire to link and interweave mathematics and mathematical literacy within computer science to ensure mathematics remained a strong component of the school's STEAM program (Genc & Erbas, 2019).

Mathematical literacy is relevant for STEAM as it empowers individuals to develop mathematical thinking, reasoning, and problem-solving skills, which are essential for success in science, technology, engineering, and mathematics fields. At the time, newly designed courses included *OS Apps Development and Android Design*, *Human Interactive Design*, *Introduction to AI*, *Web Development*, and *Coding*. Coding was a major component of CS. Coding involves the application of mathematical and computational concepts, fosters critical thinking and problem-solving skills, and is often used in conjunction with science and engineering principles to create technological solutions (Popat & Starkey, 2019). A partnership was also forged at the university level to afford students a joint high school-university CS course credit.

New course offerings continued being developed and included *Computer Programming* for utilizing algorithmic problem-solving techniques for transitioning from consumers of technology to makers of technology, *Elements of Computing Systems* (which was the school's first computer engineering course), *Exploring Computer Science* for reviewing concepts related to human-computer interaction, problem-solving, web development, and robotics, *Media Computation* for creating expressive media by manipulating computational materials (like images and sound files) for computation, *Software Design Android Apps (Software App I)* for focusing on developing and bringing *Google Android Apps to Market*, and *Web Development* for introducing students to the programming and design skills needed to create modern interactive "Web 2.0" websites and applications. CS would grow further with the development of a fully functional makers lab with Computer Numerical Control (CNC) machines, laser cutters, and 3D printers (Figure 5).

Figure 5. Laser cutter and 3D printers

ICL Makerspace

Full with Charge of the Soul

As a result of being able to re-establish CS, the school was in a unique position to not only completely revamp course offerings, but to also hire new staff with skills to deliver up-to-date CS core content. The author was also interested in creating a makerspace course and fabrication laboratory with additional emphases on coding, employing digit tools, and highlighting innovative thinking. Digital tools are interdisciplinary, interactive technologies that can be utilized across various subject areas such as mathematics, science, language arts, and social studies to enhance learning outcomes, motivation, and engagement (Alam, 2022). Coding was also a component of makerspace and supports students in developing skills such as mathematical problem solving, critical thinking, social skills, self-management, and academic proficiency (Popat & Starkey, 2019). A key benefit of makerspaces and a reason why the course was sought is its ability to engage all forms of learners, regardless of gender, background, or abilities. Research has shown utilizing a makerspace improves outcomes for underrepresented groups, such as females and students with diverse backgrounds in STEAM by sparking interest and building confidence (Konstantinou, 2021).

One of the school's newly hired computer science teachers requested a 3D printer and scanner to set up a small makerspace in a CS classroom. However, the school had a shop space that originally served as a foundry shop classroom 60-plus-years earlier before being closed and becoming a largely unused staff lunchroom. That particular space possessed a balcony that was configured differently compared to other potential learning environments (the balcony was more square than the other rooms).

An additional room was accessible just below the balcony that could be converted to privately house the makerspace's lab with its louder carvers and laser cutters. The team was excited to offer makerspace as a course for credit, as it afforded numerous benefits for students, including the opportunity to engage in hands-on, inquiry-driven projects that incorporate media arts through constructivism to construct and represent knowledge via student created work products (Dewey, 1933; Stornaiuolo et al., 2018; Vygotsky, 1978). The school was rolling out course-after-course in one redesigned creative, innovative learning space after the other. The school was also beginning to offer courses and learning environments that existed nowhere else in a district of 550 schools.

After a full year of curricular and budgetary planning, the school opened the district's first and only Human Computer Interaction Innovation Creation Lab (ICL Makerspace) housed in a 4,000 square foot facility. The ICL makerspace is a convergence of design, computer science, and art. It enables students to compose, prototype, and engineer innovative products for the world around them for deeper, personalized learning. Makerspaces help develop problem-solving skills in a hands-on and collaborative environment where students can engage in creative and open-ended projects (Hira et al., 2014). The course and learning environment serves to provide all students a forum to explore the design process and develop ideas for statements for solving problems (Stornaiuolo et al., 2018). The space also serves as a direct hub for transdisciplinary and interdisciplinary teaching and learning with computer science, robotics, mathematics, and art (Figure 6).

Figure 6. Human computer interaction innovation creation lab

Sound Engineering

The Spirit of Discovery

The school opened up the first high school sound engineering program with a fully functional state-of-the-art recording studio in the state, which was housed in a 7,000-plus square foot facility. The space was enormous and possessed enough room to afford multipurpose use for simultaneously utilizing a live room, mixing room, rehearsal spaces, and a second floor balcony with 30 Pro Tools workstations for students to edit projects. Diversifying the classroom into specialized groups that align with students' distinct musical interests allows for more tailored instruction and activities that tap into each learner's passion and motivation to drive engagement (Gage et al., 2020). Interestingly enough, the sound engineering and recording studio took residence in a space that was originally an aviation shop in the 1930's where students built airplanes (a plane was actually built in the aviation shop for the World War II war effort). The aviation shop was later converted into an auto shop in the 1960s. The school used to possess four auto shops but by 1999, there was only one remaining auto shop with dwindling student enrollment, which was eventually closed.

In addition to being a biologist, the author is also a recording musician and has been playing guitar since he was a child. A vision existed for repurposing the large, empty 7,000-plus square foot facility into a multiuse music- and physics-based sound engineering program, guitar program studio, and a music therapy space for students with special needs. Music is related to science through the study of cognitive science, neurophysiology, psychoacoustics, and cultural psychology to understand the cognitive and physiological aspects of musical perception and behavior and was a natural fit for the school's STEAM program (Cross, 1998). Dignam (2022b) stated, "Improvisation is experimentation of the spirit. Experimentation is improvisation of the mind. Free the mind and liberate the spirit (p. 44)." The goal of the program was to provide an environment for enabling students to summon their artistic abilities through a scientific approach.

There was also a demand in the school to offer additional levels of guitar as a course but there was no space to accommodate additional classes. The goal was to create a multifunctional, multipurpose use environment for hosting sound engineering, recording studio, and guitar which could take place simultaneously given the large size of the facility for fostering creativity and critical thinking. Understanding the linkages between music and science supports student understanding of scientific and social phenomena through transdisciplinary and interdisciplinary constructs such as STEAM, which enhances critical thinking and creativity for an authentic blending of art and science (Le Marec & Ribac, 2019).

The Science of Voice

A principal's Student Advisory Board (SAB) was established at every grade level. Students were a fantastic resource and representative body for learning student perspectives regarding a variety of initiatives, policies, and procedures taking place throughout the school. The author employed servant and distributive leadership with students to ensure they possessed a voice in decision-making. The SAB provided feedback and survey data for each of the new programs the school was developing and the repurposing of innovative spaces. There was genuine excitement about the prospect of creating innovative STEAM offerings for supporting academic achievement through a sound engineering program, recording studio, and expanding course offerings for guitar I, guitar II, guitar III, and adaptive music for special needs learners. Participation in music, especially instrumental music, is important for supporting academic achievement, as music positively influences exam scores in English, mathematics, and science and fosters competencies that support academic achievement (Gruh et al., 2020).

Teachers in the program were intrinsically motivated to develop and implement coursework that was innovative, creative, and included opportunities for students of all backgrounds to connect learning to their personal interests and lives. A high school sound recording program helps students make meaningful connections between school music education and students' personal musical lives by providing hands-on opportunities to create, produce, and distribute original and creative work (Clauhs et al., 2019). The administration oversaw building logistics for creating a one-of-a-kind program while teachers were provided academic freedom in designing curriculum and participating in designing spaces for eventual renovation and construction. Partnerships were also forged with external stakeholders, with whom the school would share both curricular and facility design plans for learning perspectives and for fundraising. As a result of mission and vision building, budget planning, and fundraising with internal and external partners, sound engineering and recording studio was established as the district and state's only high school sound engineering and recording studio program (Figure 7).

Figure 7. Sound engineering and recording studio

Multimedia Digital Art and Sculpture Studio

The Embrace of Love and Resistance

The school transitioned to an Apple school and initiated a new art curriculum, including a new *Film Studies* course and a variety of other STEAM courses that blended science, technology, engineering, and mathematics with digital and hands-on course offerings. The content that curricular course teams developed enabled students and teachers to not only study art but to also learn the engineering and technology side of media, as well as the science and mathematics of art project-based learning. Art and engineering are interrelated as they both involve finding answers to problems and seeking visual solutions using the design process (Bequette & Bequette, 2012). Art has influenced scientific innovation and discovery by stimulating imagination, improving observational and technical skills, fostering open-ended investigation, and positively impacting student attitudes and engagement in STEM fields (Adkins et al., 2018). The integration of computer graphics and digital art significantly impacts the art, film, and entertainment industries, allowing for the creation of convincing imaginary worlds and interactive art forms (Sickler-Voigt, 2019). Additionally, art and mathematics share qualities of giftedness, creativity, and storytelling in their works and final products (Dietiker, 2015; Leikin & Pitta-Pantazi, 2013).

The school also spent two years designing a new, Multimedia Digital Art and Sculpture Studio that was within proximity of the sound engineering program for recording and guitar, the Makers ISL for idea partnering and project design, robotics for competition and engineering, and aquaponics for urban farming. The goals for the Multimedia Digital Art and Sculpture Studio included creating a sustainable, multiuse space for meaningful hands-on, discovery-based arts curricula. Art was embedded and interwoven within STEM for an authentic STEAM program, as it contributes to STEM for STEAM by providing new ideas and creative approaches, which enhances innovation and creativity (Daugherty, 2013). Art was weaved into each new course offering to provide aesthetic perspective and to ensure each new course included creative, innovative points-of-view for design and flow.

As a result of the development of new innovative learning environments and course offerings (aquaponics, makers ICL, robotics, sound engineering, etc.), and a commitment to interweaving the arts in new, interdisciplinary STEAM curricular offerings, the art department augmented in size. Arts integration in the school's non-arts subjects supported learning outcomes by highlighting creativity, innovation, and problem-solving as core practices, leading to deep learning with benefits beyond specific disciplines (Halverson & Sawyer, 2022). While programmatic growth was wonderful, and born from solutions for reimagining curricula, the planning required to shepherd blossoming programs necessitated forward planning to ensure sustainability (Figure 8).

Figure 8. Multimedia digital art and sculpture studio

The programs that were developed were not designed to be momentary, but rather, they were created with a 10-year minimal vision and intended to be generational. All too often, principals and superintendents implement new programs, and within three years or so, they "fizzle" and then the next leader comes along to only repeat the same process. These experiences create jaded outlooks in teachers and staff and contribute to what eventually devolves into institutional inertia. When designing new courses and programs, the author mandated that courses had to be relevant for the four years students were in high school, an additional four years of college, and two more years as former students entered the job market. Possessing these criteria resulted in being able to easily discern if current course offerings were relevant, if they needed to be revised, or if they needed to be discontinued. The criteria employed also determined whether new course proposals possessed merit.

Reflections on the Many Facets of Learning

From the Author…

During the visioning, development, and implementation of our STEAM program, as teachers would construct curricular plans or propose space utilization proposals, I would review and push the curriculum and space design teams further by predictably stating, "We can do more than that." It became a somewhat predictable (and humorous) pattern, as we understood one another, and when educators feel valued and heard, they are more willing to "go back to the drawing board" to imagine with greater depth and breadth. The end results were imaginative curricular and space designs that captured the aesthetics of experimentation for conceptualizing and actualizing a STEAM program to support teaching and learning for all.

I was once asked by one of my doctoral students how I would summarize the role of an educational leader. She wanted to know my perspective through my lens of experiences. I replied with an analogy that has evolved over the years into a formal poem I now read to each new cohort of students. I later created a mural of my *thoughts and words, which I have proudly displayed ever since in my recording studio, as well as in my office (Figure 9).*

It reads, "Every educational leader is an artist. I am the artist and the community is the palette. I hold the brush and blend colors into facets of learning. My canvas is the school. I render a community of practice, designing opportunities for teachers to teach and for parents to be involved. Learners own the canvas. For everything I paint is for students" I hope you would agree (Dignam, 2022a).

Figure 9. The art of leading (Dignam, 2022c)

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What Could be the Role of Artificial Intelligence in STEM Education in the 21st Century?

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Introduction

The World has seen too many changes after industry age started in 18th century. During the first phase of industrial revolution, the use of machines in the factories instead of body power was really a revolution. The advent of machines with the use of coal increased the efficiency of those factories. The number of productions increased by using these plants. Besides, the second phase of the industrial revolution started in the 19th century shows us the use of technology in manufacturing proceses. Clark (2014), Steam power in England certainly touched a number of areas in the Industrial Revolution. It was important in coal mining, on the railroads, and in powering the new textile factories. The steam engine itself underwent a long process of improvement in thermal efficiency, and in the ratio of power to weight, from its first introduction by Thomas Newcomen in 1707–1712, to the 1880s. The earliest engines had a thermal efficiency as low as 0.5%, while those of the 1880s could achieve thermal efficiencies of 25%. The steam engine was associated also with the widespread use of fossil energy in the economy to replace wind, water, and animal power sources in transport, home heating, and manufacturing. In the 20th century we saw the rapid changes in industry by using electricity and this was the third phase of the industry. Today, in 21st changes we feel have an ongoing process and in our daily life everything is changing very fast. This era is also called the fourth Industrial Revolution. Philbeck and Davis (2019), Framing the Idea of the Fourth Industrial Revolution in January 2016, World Economic Forum Founder and Executive Chairman, Klaus Schwab, published a book titled The Fourth Industrial Revolution. Since then, the term “Fourth Industrial Revolution” (4IR) has been used to frame and analyse the impact of emerging technologies on nearly the entire gamut of human development in the early 21st century, from evolving social norms and national political attitudes to economic development and international relations. The concept of the Fourth Industrial Revolution affirms that technological change is a driver of transformation relevant to all industries and parts of society. Furthermore, it highlights the idea that, at certain stages in history, sets of technologies emerge and combine in ways that have impacts far beyond incremental increases in efficiency.

We may say that those technology-based changes have showed themselves very much in the fields of education. It is known that both AI and STEM Education have gained popularity in education after 2000s.

STEM Education

Science, technology, engineering, and mathematics education has commonly been referred to as STEM education in the United States since the early 1990s (Sanders, 2009). For some scholars STEM is basically a replacement term for science or mathematics (Breiner et al., 2012). Other scholars think that STEM refers to a more integrated approach to teaching and learning that necessitates open connections between disciplinary content and practices (Honey, Pearson, & Schweingruber, 2014; Kelley & Knowles,2016). Pitt (2009) states that while some people define any activity that involves any of science, technology, engineering or mathematics as a STEM activity, others address that intrinsic to the concept is some linking of two or more of the component areas of learning, and that real STEM should be more than the sum of STEM's parts.

STEM education provides an experience that allows students to acquire knowledge and skills in science, technology, engineering, and mathematics in the course of solving real-life problem situations and use them meaningfully in their lives (Gonzalez and Kuenzi, 2012). This explains why we need to include STEM Education and its activities into the school curricula. STEM Education allows students to gain 21st century skills including to have required skills for their future professional careers. According to Chng, Tan, & Tan (2023), "While justifications have been made for emerging technologies' transformative potential in STEM education, the roadmap for their eventual implementation in schools is underexplored.

Artificial Intelligence

AI is considered to have effect all areas such as politics, culture, education, economy in modern society (Chen et al. 2020). These fields are being affected by AI and today it can be seen that its effect has increased. The term 'artificial intelligence' was first used at a 1956 workshop held at Dartmouth College to describe the "science and engineering of making intelligent machines, particularly intelligent computer programs (McCarthy et al., 2006). Since then, many developments have been developed in AI based technology platforms and tools (Dönmez, Idil, Gulen, 2023). Luckin et al. (2016) define AI as it is as computer systems that have been designed to interact with the world via abilities that we generally think of as human. AI can be divided into two primary categories. These are narrow AI and general AI (Russel and Peter, 2016). While Narrow AI is programmed to carry out special tasks such as online or facial recognition searches, General AI has the potential capacity to execute any cognitive task a human could do. Generative AI particularly refers to a class of artificial intelligence models that use existing data to prepare new content that mirrors the highlighting patterns of the real-world data (Gong, 2016; Relmasira, Lai and Donaldson (2023). A diverse range of AI technologies are currently in use internationally. Besides, there is a growing recognition of the significance of AI in the context of labour and in terms of its impact on daily life (UNESCO, 2022).

Pelletier et. al (2022) the continued growth of artificial intelligence (AI) is influencing every industry including education. AI has played a significant role in the advent of the fourth industrial revolution. In recent years, AI has gradually been revolutionizing education. Educational systems are adopting AI tools to support methods of instruction that benefit students. Since the covid-19 pandemic, AI for learning tools is viewed as a key technology having a significant impact on higher education. AI has the potential to deal with some of the biggest difficulties in education today, innovate teaching and learning practices, and ultimately accelerate the progress towards Sustainable Development Goal 4. But these rapid technological developments unavoidable bring multiple risks and challenges (UNESCO, 2021).

In figure 1, it is given the relationship AI with Machine Learning (ML), Neural Networks (NN) and Deep Learning (UNESCO, 2021).

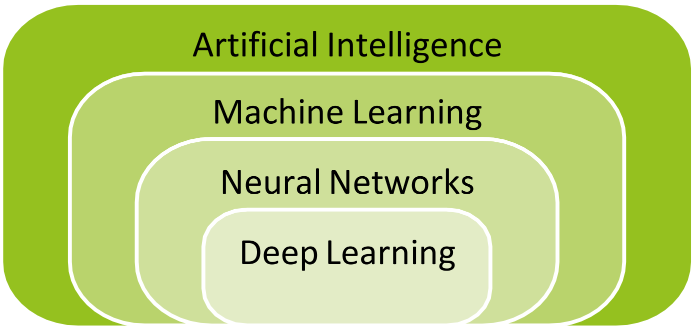

Figure 1. The relationship between AI, ML, NN and DL

Figure 1 reveals the relationship AI with its approaches which have been used in AI based applications. ML, analyses large amounts of data to determine designs and create a model which is later used to predict future values. NN is inspired by the structure of biological neural networks. DL refers to NN that consist of multiple intermediary tiers. It has led to latest remarkable applications of AI. Within AI approaches, there can be seen some AI technologies to be used today such as Natural Language Processing (NLP), Speech Recognition, Image Recognition and Processing, Autonomous Agents, Affect Detection, Data Mining for Prediction, Artificial Creativity (UNESCO, 2021).

Teaching young learners about the basics of AI not only enhances broader skills such as critical thinking, meaning-making Xia et al (2022), and understanding of how computers function, but it also provides them with prospects to transfer that understanding to other contexts. As a result, AI has been identified as a critical skill for the next generation to succeed as future creators and innovators Ma et al. (2023).

The introduction of AI into educational fields might be traced to the 1970s. During that time, researchers were interested in seeing how computers might substitute for one-to-one human tutoring (Bloom, 1984). AI technologies have been used to facilitate the management and delivery of education. These systems have been facing applications are designed to automate aspects of school administration, building on Education Management Information Systems (Villanueva, 2003). Since 2000s AI has been used in educational fields with different purposes. Connor (2018) AI tools are used to address students' attention while teaching and learning process. Beside this, Harwell (2019) states that it is used for track attendance including predict teachers' performance (O'Neil, 2017).

Artificial Intelligence in STEM Education

Artificial intelligence (AI) is considered a STEM subject. Although AI is heavily based on computer science (CS), it is an interdisciplinary field that makes it transcend across subjects, including non-STEM courses. The transdisciplinary nature of AI further increases the interest it currently generates globally; that is, its key role in driving growth and innovation across industries, including the education sector. With the increasing utilization and relevance of AI in almost every facet of human lives, there have been calls to introduce AI into the formal K-12 curriculum

Touretzky et al 2019; Sanusi et al 2022). Rodrigo et al (2021) There is a growing trend of promoting STEM education for cultivating students' creative mindset and cross-disciplinary ability to create artifacts that solve problems of humankind and serve human needs. There is an increasing attention to the promotion of AI literacy education for cultivating students' ability to solve problems through the use of computers for automating parts of the problem-solving processes in a manner comparable with humans' processes. This creates an emerging need for planning curriculum initiatives across different educational sectors to meaningfully engage students in co-developing AI literacy and STEM knowledge for their success in the digital era. They also stated that the panel will provide an insightful discussion about an international perspective in relation to the role of AI in STEM education.

While there is agreement about the importance of AI lessons in schools across grade levels, less attention has been given to teachers and teacher education programs. The learning process of AI education requires students to combine knowledge from different fields. Hence, incorporating AI learning into STEM education is worthwhile at this moment because STEM education focuses on interdisciplinary learning experiences. Previous studies have identified the trend of incorporating STEM integration into education to foster future citizenship in science (Li et al., 2020). For the next generation, we can need to focus more on new kind of jobs due the developments seen in the technology and its fields. To be able to equip today's young people we should donate our students with 21st century skills such as creativity, critical thinking, entrepreneurship, efficient problem-solving, communication and including Chiu and Yeping (2023) AI literacy, leaderships and collaborative skills. STEM Education and AI education can be stated as they are global educational initiatives for K-12 (Casal-Otero et al., 2023; Chiu et al, 2022).

Relmasira, Lai and Donaldson (2023) states that while experiences exposing students to AI are valuable, education alone does not equip them with the required knowledge and skills to understand, use, and evaluate AI technologies in an ethically appropriate manner. Triplett (2023) The application of Artificial Intelligence (AI) has become increasingly significant in various sectors, such as healthcare and education. Within

STEM (Science, Technology, Engineering, and Mathematics) education, AI has played a crucial role in facilitating personalized learning, advanced analytics, and instructional automation. Despite the potential advantages that AI offers to STEM education, there is a lack of comprehensive and empirical studies that thoroughly examine the real impacts, integration challenges, and pedagogical approaches associated with its implementation in this domain.

With the development of computer science and computational technologies, automatic, adaptive, and efficient AI technologies have been widely applied in various academic fields. Artificial Intelligence in Education (AIEd), as an interdisciplinary field, emphasizes applying AI to assist instructor's instructional process, empower student's learning process, and promote the transformation of educational system (Chen et al., 2020; Holmes et al., 2019; Hwang et al., 2020; Ouyang & Jiao, 2021). But existing literature review of AIEd has mainly focused on the trends, applications, and effects of AIEd from a technological perspective (Chen et al., 2020; Tang et al., 2021; Zawacki-Richter et al., 2019). It is seen that AI could be applied in some fields of the education. At this point, we can include AI into STEM Education. Although AI has the potential to enhance the instruction and learning in STEM education (Chen et al., 2020; Holmes et al., 2019), the development of AI-STEM requires a better fit between AI technologies and other system elements in STEM education. Since STEM education contains interdisciplinary knowledge and learning contents from different subjects, AI is usually restricted in specific learning contents or courses (Douce et al., 2005). It can be claimed that there are some challenges to adapt AI into STEM Education curricula with required contents. For instance, when AI is applied in STEM education, the role of instructor is expected to shift from a leader to a collaborator or a facilitator under the AI-empowered, learner-as-leader paradigm (Ouyang & Jiao, 2021). However, this review found that the instructor- centered lecturing mode was the most frequently used instructional strategy in AI-STEM studies, while other student-centered instructional strategies (e.g., the project-based learning, collaborative learning, gamebased learning) appeared infrequently. One of the reasons centers on the complexity of integrating technology and pedagogy in STEM education (Castañeda & Selwyn, 2018; Jiao et al., 2022; Loveless, 2011). For example, ITS and automation techniques are usually designed based on behaviourism (Skinner, 1953) to support instructor's knowledge delivery and exam evaluation, which may be challenging for instructors to use when integrating it in the student-centered instructional strategies.

To be able to deal with those mentioned challenges there can be used some technology-based apps and tools. If the AI based apps can be used in harmony with the other technological tools and apps, T-the challenges of integrating artificial intelligence into stem education can be overcome. Chng, Tan, Chee and Tan (2023) On the surface, the fast-paced development of new technologies that can help address educational issues seems like a blessing, but this deluge of new technologies presents an unexpected conundrum for educators in reality. To begin with, the incorporation of any new technology into an existing curriculum requires substantial reworking and attention to detail. Also, teachers need to be adequately trained to be able to use these new technologies in classrooms effectively. As well, the deployment of new technologies might require infrastructure or resources that schools lack. Therefore, given the significant amount of investment in effort and resources in deploying a new technology, it is impractical for educators to adopt every piece of emerging technology that comes with every wave of technological innovation. With this in mind, this review aims to examine the use of emerging technologies in schools to deepen our understanding of how emerging technologies can be deployed, unpack the educational role of emerging technologies, and understand the inherent value that emerging technologies bring in transforming teaching and learning.

Jang, Jeon and Jung (2022), in their study, revealed the relation between STEM Education and AI. They looked for research trends in both STEM Education and AI which were done between 2019 and 2022. STEM, STEAM and AI Education were used to determine the latest trends in those fields. During this time, they benefit from some concepts, as keywords such as AI, Machine Learning, Deep Learning, Higher Education, Big Data, STEM, STEAM, Technology, Internet Things and e-learning.

They found that some concepts' occurrences were higher than the other keywords. For instance, AI Education 617, Education 172, Machine Learning 150, Deep Learning 71. Besides, they also prepared the analysis of the articles about AI education and STEM from 2019 to 2022. The detailed figure is given below.

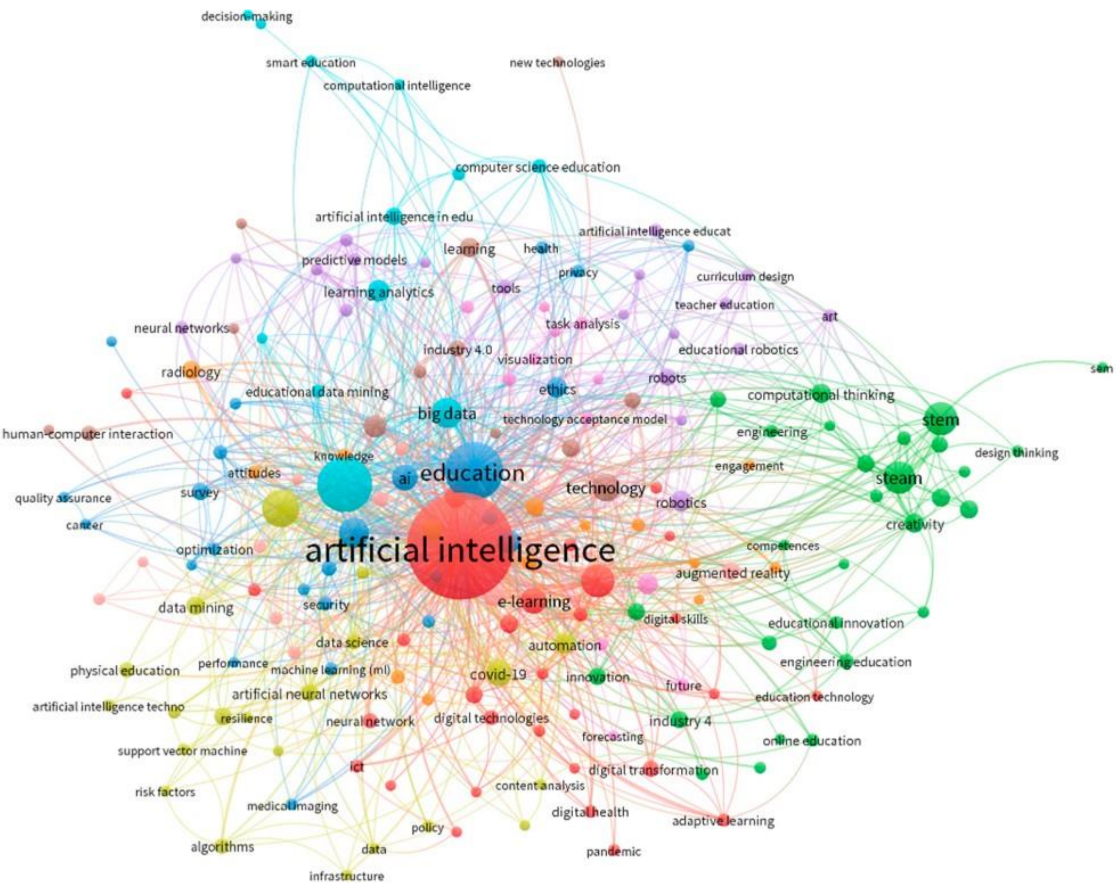

Figure 2. The analysis of articles about AI education and STEM from 2019 to 2022

In figure 2, it is seen that many related concepts for STEM and AI Education are given. In relation with AI, machine learning, security, data science, data mining, neural networks, vector machine, human computer interaction and automation are related subjects under AI Education. Within STEM, there are some concepts such as education, technology, Industry 4.0, engineering education, design thinking, computational thinking, innovation, robotics, engagement, online education, adaptive learning and new technologies.

To be able to prepare a curriculum/educational programme based on both STEM Education and AI it should be included all details within those two fields. In this context, the relation between STEM Education and AI should be addressed very well and the content of them could be included into the curriculums/educational programmes. For making this, we can benefit from some tools and instruments as given below.

Hardware and Technical Materials

Within this category both AI and STEM based tools can be used together. The hardware includes computers, laptops, tablets, internet access. By using those materials some robotic and electronic kits/devices can be used. Within this context, it is known that some technological devices such as Lego Spike Prime, Lego Mindstorm, LEGO EV3, Raspberry pi27, Arduino are being used in STEM Education based curriculums and educational programmes.

Software

To build IT storage infrastructure and reducing storage costs, UNESCO (2022) the Ubuntu open-source operating systems were used by some curricula as less expensive to other operating systems.

Programming Languages

It is understood that some important programming languages are widely used in STEM Education based programmes. Those programming languages are Python, Micropython, Javascript, C++, HTML, Scratch.

Databases: Databases are used when the development of data-depended AI tool is necessary. It is simply because that learners might be able to test the programs and optimize the algorithms such as ImageNet and Coco.

Tools for learning AI techniques

Some tools can be used within AI to facilitate learning process and make understand AI. Following tools can be given as examples regarding AI; Keras, OpenVINO, Teachable Machine, TensorFlow and MachineLearningForKids.

Discussion and Conclusion

In this study, the relation between STEM Education and AI is being tried to address within educational context. In recent years, the importance use of AI and STEM Education continue to increase all over the world.

It is seen that some international organisations such as European Union, UNESCO have been focusing on those two fields. Besides, countries have also been using and including them into educational curriculums. Although these significant efforts to be done in curriculums, it can also be said that the expected outputs have not been seen for those countries which developed STEM Education based curriculums. To be able to address this challenge, it is recommended that AI and STEM should be given into educational curriculums with harmony.

Jang, Jeon and Jung (2022) found that STEM-based Artificial Intelligence in Education (AIED) program had a positive effect on K-6 pupils' creative problem-solving ability and basic literacy and attitude toward AI. Based on this study, we can claim that policy makers and educational officials should include STEM-based AI contents into curricula and also prepares original curriculums that comprise STEM and AI. It is also recommended to add "A" into STEM so that students can enhance their creativity after teaching and learning process. By using AI in STEM curricula can enhance students' 21st century skills and prepare them for their future professional career. Hence, they can be equipped with necessary skills which business world will need in the near future. Although countries have some important experiences with the use of AI and STEM Education. There is still long way to go for those two fields. Therefore, all stakeholders should work together to increase the efficiency of the AI in STEM Education for students within K-12 level.

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Chapter 8

Social Media Presence and Its Impact on Relational Communication

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Introduction

Considering the fact that communication and interpersonal relationships are interconnected the term relational communication suggests that the communication derives from the interaction of the different members of the society (Rogers, 2008). In the 21st century when the society gains the sense of connectedness through social media presence the attitudes and perceptions in terms of connection between the communication peculiarities influenced by virtual communication becomes more actual.

While Baby Boomers and Generation X are especially worried about the usage of different gadgets by younger generations delivering attention to the outcomes is important.

Mankind nowadays lives in the Information Era and Gen Z is the product of it, they have never lived without technology, which means that virtual communication is as part of their life as face-to-face. They are used to “high-tech and multiple information resources, with messages bombarding them from all sides” (Williams & Page, 2011).

According to different researches Gen Z cares about the belonging, their ideas and experience are wider. “Their self-concept is partially determined by the group to which the Tween belongs” (Williams & Page, 2011). They are bolder ones and believe that they can change the world.

Digital Era

Significance of digital era is crucial in the contemporary world. In today’s world, virtually every individual in technologically advanced societies experiences the pervasive presence of digital technologies, subtly impacting diverse facets of our daily routines. Frequently, these technologies have emerged with the aim of enhancing convenience and efficiency in our lives. The widespread and rapid adoption of social networking platforms like Facebook, WhatsApp, YouTube, Instagram, LinkedIn and TikTok has guided new possibilities, that caused and created a revolution in communication in our lives. In accordance with Kaplan et al. in the current era, social media plays a central role for many business executives (Kaplan & Haenlein, 2010). The book entitled “How the World changed Social Media” describes so-called “digital natives” and the world’s transformation due to social media swift growth (Miller, et al., 2016).

“As of October 2023, there were 5.3 billion internet users worldwide, which amounted to 65.7 percent of the global population. Of this total, 4.95 billion, or 61.4

percent of the world's population, were social media users" (Ani Petrosyan, 2023). In 2022, the typical daily social media consumption for global internet users averaged 151 minutes, marking an increase from the preceding year's 147 minutes.

The term "social media presence" denotes the extent to which user or brand is represented across various social media platforms. It goes beyond mere visibility and encompasses how the user or company presents itself and shapes its image through the social media channels. Organizations are integrating social media into their strategies for marketing, advertising, employee recruitment, and comprehensive communication with employees, clients, and partners. Positive Social media dialogue is essential tool for both organizations and individual users.

According to Karampela et al. findings, the supplier's active engagement on Twitter, LinkedIn, and Facebook contributes positively to all four indicators (commitment, intimacy, satisfaction, and partner quality) of brand relationship strength (Karampela, Lacka, & McLean, 2020). Enhanced interactivity is associated with an improved perception of partner quality, and responsiveness plays a crucial role in fostering commitment.

The youth as active users of social media are sociable ones and appreciate communication. Despite the thing that they feel more courageous in virtual space they prefer facto-face communication. The negative side of social media presence is that it increases aggression, there are number of people "following" someone they do not know. More than that, due to the continuous updates of different social platforms you do not even always need to "follow" someone to be part of his/her life. Probability of meeting the content on the platforms not acceptable or interesting for some representatives of the society might annoy them and express aggression towards others.

Relational Communication in a Long Live Digital Era

Due to the profound significance of relationships in individuals' lives, scholars have invested considerable time and energy to unraveling the origins and mechanisms of interpersonal relationships. In the dynamics of relationships, communication stands as the foundational process that molds and defines the connections between individuals. "Communication creates and sustains relationships and, as well, that relationships shape both the enactment and interpretation of communication" (Sillars & Vangelisti, 2018).

Relational Communication Theory defines communication as a social phenomenon, representing the vital essence of our humanity. It serves as the mechanism through which we engage with others, collaboratively construct social realities, and shape both relationships and our individual identities (Rogers, 2008).

As mentioned before, in the current era dominated by digital advancements, our daily existence is profoundly influenced by the pervasive presence of digital technologies. Correspondingly, the landscape of communication has been transformed with the rise of social media, creating a distinct wave in connectivity. Social media platforms provide free space for sharing and gaining information, they enhance the immediacy of communication and provide forums for public perspectives on a range of issues. (Wright & Hinson, 2009, p. 27)

The rise of social media has fundamentally altered the dynamics of human connection, communication, and relationship maintenance. Although these platforms provide unparalleled chances for staying linked, they also bring forth a nuanced spectrum of impacts on personal relationships, encompassing both favorable and adverse aspects.

People employ social media platforms within a variety of relationships. Friends share images and video clips, consumers engage with both each other and representatives from organizations offering products and services, and research collaborators, coordinate and carry out projects. Meanwhile, family members utilize these platforms to disseminate news about achievements and significant life events. In every instance, individuals harness the fundamental capabilities of social media systems to facilitate communication, exchange information, and share digital content, all in support of their respective relationships.

“Social media are a diverse collection of technologies and applications that allow individuals to communicate, exchange information, and share digital artifacts with one another. These basic capabilities can be appropriated to support many different types of relationships. Whether creating substitute relationships, enabling new types of relationships, or complementing existing relationships, social media systems are important influences on the way people and organizations relate to one another in all spheres of life” (Butler, The International Encyclopaedia of Digital Communication and Society, 2015).

Despite several negative aspects, social media can’t be considered negative, since thanks to its presence in our lives we can delete distances in many cases. Not only in terms of personal communications, but in business context as well social media and virtual communication have very important role – it makes communication easier, saves time, fosters more courage, etc.

Social Media Impact on Relation Communication

The way people communicate has been reshaped by social media, leading to a decline in the occurrence of face-to-face connections. Face-to-face communications transformed into long drawn written communications. Nowadays, computer-mediated communication (CMC) has surpassed face-to-face interactions in both significance and convenience (Venter, 2019). The advantages provided by this form of social media include immediate global connectivity and convenient accessibility. As communication speeds up, the world appears to contract, making instant contact across the globe easily achievable. The ability to facilitate the creation of new connections that transcend geographical, political, and social divides stands as a key incentive for the transformative influence of social media on both organizations and society (Butler & Matook, 2015).

As mentioned previously social media has opportunity to spread a big amount of information in very short period, that bombards the users in many cases during the time they are not ready to receive and digest it accordingly. This causes difficulties in communication, since some people lose perception of reality. Besides, privacy is lost when everyone know everything about others, this may cause some mental problems (Subramanian, 2017).

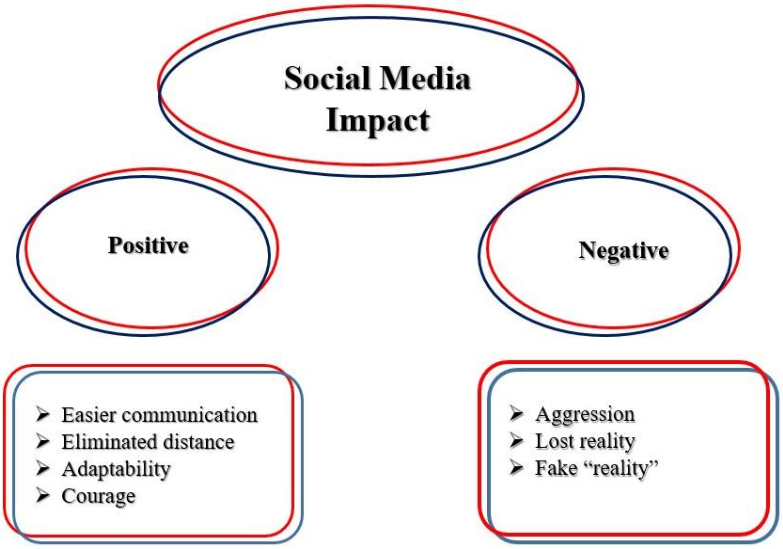

Figure 1. Social media impact on human interaction

The research conducted on the Georgian market showed that despite feeling comfortable in virtual space Gen Z still prefers face-to-face communication exactly for the same reason mentioned above. They consider that social media hinders from understanding the reality, moreover, in many cases information spread there is fake.

Conclusion

As social media and virtual communication gains more popularity and penetrates in different aspects of human lives new challenges also arise. Communication on social media necessitates varied skills and techniques of communication unlike face-to-face communication (Kazaishvili & Khmiadashvili, 2022). Technology and mobile communication is very actively used by the society, especially by youth to develop relationships in different contexts (Pettegrew & Day, 2015).

Gen Z as very active and hard-to-imagine-without-technology generation still chooses face-to-face communication even though virtual space gives them more courage and confidence. Although social media makes communication easier, it still causes multiple misunderstandings and misleading, thus might have damaging affect as well. Different angles of virtual communication in terms of influence on relational communication were identified:

1. Social media/virtual communication simplifies the communication process
2. Virtual communication changes communication language
3. Virtual communication develops better communication skills for face-to-face communication.

Accordingly, despite several negative aspects positive impact is obvious to improve relational communication.

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A Comparative Analysis of Technology Integration in Urban and Rural Educational Settings in The Gambia

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Introduction

In the ever-evolving landscape of education, the integration of technology stands as a transformative force, shaping the learning experiences of students across diverse settings. This paper undertakes a comprehensive comparative analysis, focusing on technology integration in educational environments in The Gambia, with a specific emphasis on the distinctions between urban and rural contexts. As we delve into this exploration, we draw inspiration and insights from the recently released 2023 West Africa Senior Secondary School Certificate (WASSCE) results by the Ministry of Basic and Secondary Education (MoBSE). These results not only mark a significant milestone in the academic journey of Gambian students but also provide tangible data to inform our understanding of the challenges and achievements in the educational landscape.

The educational journey in The Gambia, as reflected in the WASSCE results, is characterized by a dynamic interplay of various factors, including gender dynamics, disparities in subject performance, and the influence of Technical and Vocational Education and Training (TVET) subjects. The overarching goal of this paper is to conduct a nuanced analysis of how these factors intersect with the integration of technology, shedding light on the intricate web of challenges and opportunities present in both urban and rural educational settings.

As technology becomes increasingly vital for educational equity and socio-economic development, it is imperative to address the existing disparities between urban and rural areas. Infrastructure limitations, variations in internet connectivity, and differences in resource availability play pivotal roles in shaping the accessibility and effectiveness of technology integration. By juxtaposing these challenges against the achievements highlighted in the WASSCE results, we aim to contribute valuable insights that can inform policies, guide educators, and engage stakeholders in fostering inclusive and effective technology integration.

The following sections of this paper will delve into the specific nuances of technology integration in urban and rural educational settings, exploring pedagogical approaches, the impact on student engagement and learning outcomes, and proposing solutions to bridge the digital divide. Through this exploration, we strive to align our findings with the national goals of achieving educational equity and socio-economic development in The Gambia.

Literature Review

The release of the 2023 West Africa Senior Secondary School Certificate (WASSCE) results by the Ministry of Basic and Secondary Education (MoBSE) marks a pivotal moment in the academic landscape. This literature review examines key themes emerging from the announcement, contextualizing the findings within the broader discourse on educational assessment, gender equity, and the importance of Technical and Vocational Education and Training (TVET).

Educational Assessment and Academic Achievement

The announcement of WASSCE results underscores the ongoing importance of educational assessments in gauging student performance and program effectiveness. Research highlights the significance of standardized testing in providing insights into academic achievement, shaping educational policies, and facilitating data-driven decision-making (Koretz, 2008). The observed increase in candidates meeting university entry requirements and the specific improvements in Technical and Vocational Education and Training subjects point to the multifaceted nature of academic achievement.

Gender Disparities and Achievements

The notable gender disparities in WASSCE results align with global discussions on gender equity in education. Studies emphasize the multifaceted challenges faced by girls in accessing and excelling in education (UNESCO, 2021). The commendable achievements of girls, representing 60% of candidates and 53% of those attaining 5 credits or more, reflect the positive impact of initiatives promoting gender equality in education.

Challenges in English Language Proficiency

The consistent decrease in performance in English language over the past three years highlights a persistent challenge in language proficiency. Research acknowledges the centrality of language skills in academic success (Cummins, 2017). The commitment of MoBSE to address this issue aligns with existing literature emphasizing the importance of language enhancement programs to improve overall educational outcomes.

TVET and Diversification of Educational Opportunities

The success of students in Technical and Vocational Education and Training subjects emphasizes the importance of diversifying educational opportunities. Research supports the notion that a robust TVET sector contributes to economic development, enhances employability, and addresses skills gaps (Sultana, 2019). The high pass rates in Auto Mechanic, Applied Electricity, Woodwork, and Clothing and Textile underscore the potential of TVET to provide viable career pathways for students.

Commitment to Equitable and Quality Education

The commitment of MoBSE to nurturing talents, promoting gender equity, and addressing challenges in language proficiency aligns with global efforts to provide accessible, equitable, and quality education (UNESCO, 2020). The literature underscores the need for continuous efforts in creating inclusive learning environments that cater to diverse needs and fostering a commitment to lifelong learning.

In conclusion, the 2023 WASSCE results, as announced by MoBSE, contribute to the ongoing discourse on educational assessment, gender equity, and the role of TVET in shaping academic outcomes. The nuanced perspective offered by the results provides valuable insights for policymakers, educators, and stakeholders, emphasizing the importance of tailored interventions to address challenges and celebrate achievements in the educational landscape.

Methodology

Data Source: 2023 WASSCE Results by MoBSE

The primary data source for this comparative analysis is the 2023 West Africa Senior Secondary School Certificate Examination (WASSCE) results provided by the Ministry of Basic and Secondary Education (MoBSE). These results offer a comprehensive overview of the academic performance of students, serving as a foundational dataset for our examination of technology integration in urban and rural educational settings in The Gambia.

Selection Criteria for Urban and Rural Settings

To delineate the distinctions between urban and rural educational environments, a careful selection process was employed. Urban and rural settings were identified based on established criteria, including population density, geographical location, and administrative classifications. This systematic approach ensured a representative and meaningful comparison between the two settings, allowing for a nuanced analysis of the impact of technology integration.

Analysis of Infrastructure, Internet Connectivity, and Resource Availability

The comparative analysis incorporated an in-depth examination of infrastructure, internet connectivity, and resource availability in both urban and rural educational settings. This involved assessing the presence and functionality of technological resources such as computer labs, access to the internet, and availability of educational materials. Disparities in infrastructure and resources were systematically documented to provide insights into the contextual factors influencing the integration of technology.

Integration of Real-world Data into Comparative Analysis

Real-world data, specifically the 2023 WASSCE results, were seamlessly integrated into our comparative analysis. By aligning academic performance metrics with the identified urban and rural settings, we aimed to correlate educational outcomes with the technological landscape. This integration facilitated a data-driven exploration of the challenges and opportunities associated with technology adoption, enriching the analysis with tangible insights from the academic achievements of Gambian students.

This methodological framework ensures a robust and systematic approach to our comparative analysis, combining official examination results with on-the-ground assessments of technological infrastructure and resources in urban and rural educational settings. The meticulous selection criteria further enhance the validity and relevance of our findings.

Technology Integration in Urban Educational Settings

Infrastructure and Resource Availability

In urban educational settings, the analysis of infrastructure and resource availability revealed a landscape characterized by robust technological support. Well-equipped computer labs, modern classrooms with multimedia facilities, and access to cutting-edge educational resources were prominent features. The presence of such infrastructure signifies a conducive environment for technology integration, enabling educators to leverage advanced tools and materials in their teaching methods.

Internet Connectivity

Internet connectivity in urban areas exhibited a higher degree of reliability and speed. High-speed broadband and widespread Wi-Fi accessibility contributed to seamless online activities, fostering an environment conducive to e-learning and collaborative online initiatives. This enhanced connectivity facilitated real-time communication, access to online educational platforms, and the utilization of web-based resources for both educators and students.

Pedagogical Approaches

Urban educational settings showcased diverse pedagogical approaches aligned with technology integration. Educators leveraged interactive software, multimedia presentations, and online collaborative tools to enhance the learning experience. Blended learning models, combining traditional teaching methods with digital resources, were prevalent. The dynamic use of technology in lesson planning and delivery reflected a forward-looking approach to education in urban environments.

Impact on Student Engagement

The integration of technology positively impacted student engagement in urban educational settings. Interactive and multimedia-rich learning experiences captured students' attention and encouraged active participation. Online forums, virtual discussions, and collaborative projects facilitated peer interaction, fostering a sense of community among students. The availability of digital resources also allowed for personalized learning experiences tailored to individual student needs.

Learning Outcomes

The influence of technology on learning outcomes in urban settings was evident in the 2023 WASSCE results. Students exposed to integrated technological tools demonstrated proficiency in subjects that required digital literacy. The positive correlation between technology integration and academic success underscored the role of advanced educational technology in enhancing the overall learning outcomes of students in urban educational settings.

The analysis of technology integration in urban educational settings highlights a technologically enriched environment with robust infrastructure, reliable internet connectivity, innovative pedagogical practices, increased student engagement, and positive learning outcomes. These findings contribute to a comprehensive understanding of the dynamics shaping educational experiences in urban areas, guiding future strategies for technology integration in educational settings.

Challenges and Opportunities

"Dissecting Challenges in Technology Integration"

Urban-specific Challenges

In urban educational settings, while technology integration has showcased significant strides, certain challenges persist:

Digital Disparities

Despite robust infrastructure, disparities in technology access among urban students may exist due to economic factors. Ensuring equitable distribution of resources is crucial to bridge this gap.

Pedagogical Adaptation

Rapid technological advancements may pose challenges for educators to keep pace with evolving tools and methodologies. Continuous professional development is vital to ensure teachers effectively leverage technology for enhanced learning experiences.

Overemphasis on Hardware

The focus on acquiring advanced hardware may overshadow the importance of pedagogical strategies. Balancing investments between infrastructure and teacher training is essential for maximizing the impact of technology on education.

Rural-specific Challenges

In rural educational settings, the challenges associated with technology integration are distinct:

Limited Infrastructure

Outdated facilities and inadequate resources in rural areas hinder the seamless integration of technology. Addressing infrastructure gaps, including the provision of functional computer labs, is paramount.

Connectivity Constraints

Uneven internet connectivity and limited access to high-speed broadband impede the effectiveness of online learning initiatives. Collaborative efforts are needed to expand reliable connectivity and bridge the urban-rural digital divide.

Resource Scarcity

The scarcity of cutting-edge educational resources in rural schools may limit the diversity of technological tools available for teaching and learning. Initiatives focused on providing digital learning materials can mitigate this challenge.

Opportunities for Improvement

Strategies to Address Urban Challenges

Equity-focused Resource Allocation

Implementing policies that ensure equitable distribution of technological resources among urban schools, regardless of economic disparities, promotes inclusive access to educational tools.

Holistic Teacher Training Programs

Developing comprehensive professional development programs for urban educators, emphasizing both hardware and pedagogical skills, ensures a holistic approach to technology integration in the classroom.

Curriculum Alignment

Aligning the curriculum with evolving technological trends ensures that students are prepared for the demands of the digital age. Regular curriculum reviews and updates can enhance the relevance of technology in urban education.

Solutions for Overcoming Rural Limitations

Infrastructural Investments

Prioritizing investments in rural infrastructure, including the establishment of functional computer labs and the provision of modern educational facilities, is fundamental for overcoming limitations in technology integration.

Community-driven Connectivity Initiatives

Engaging local communities in developing solutions for improved internet connectivity can lead to sustainable outcomes. Collaborative efforts between government, private entities, and communities can address connectivity constraints.

Digital Resource Mobilization

Initiatives aimed at mobilizing digital resources, including educational software and online learning materials, can supplement the scarcity of physical resources in rural areas, enriching the learning experience for students.

In navigating these challenges and capitalizing on opportunities, a nuanced and context-specific approach is essential. By recognizing the unique dynamics of both urban and rural educational settings, stakeholders can develop tailored strategies that foster inclusive, equitable, and effective technology integration, thereby contributing to the overarching goals of educational advancement in The Gambia.

Conclusion

Summarization of Key Findings

In conclusion, our comprehensive comparative analysis of technology integration in urban and rural educational settings in The Gambia has yielded several key findings:

Urban Advancements

Urban areas exhibit robust infrastructure, reliable internet connectivity, and innovative pedagogical approaches, leading to positive student engagement and improved learning outcomes.

Rural Challenges

Rural settings face challenges stemming from limited infrastructure, connectivity constraints, and resource scarcity, resulting in disparities in technology access and learning outcomes.

Gender Equity

Despite challenges, commendable achievements in gender equity were noted, with girls representing a majority of candidates and excelling academically.

TVET Success

Technical and Vocational Education and Training (TVET) subjects demonstrated high pass rates, emphasizing the importance of diversifying educational opportunities.

Recommendations for Future Policies and Interventions

To address the identified challenges and build on the opportunities presented, the following recommendations are put forth:

Equitable Resource Allocation

Ensure equitable distribution of technological resources, focusing on both urban and rural schools, to bridge the digital divide and promote inclusive access.

Professional Development

Implement targeted professional development programs for educators, emphasizing technological competencies and pedagogical strategies to enhance the integration of technology in teaching.

Infrastructure Development

Prioritize investments in rural infrastructure, including the establishment of functional computer labs, to create a conducive environment for technology integration.

Connectivity Initiatives

Collaborate with local communities, government entities, and private sectors to develop sustainable solutions for improving internet connectivity in rural areas.

Curriculum Review

Regularly review and update the curriculum to align with technological advancements, ensuring students are well-prepared for the challenges of the digital era.

Acknowledgment of MoBSE's Commitment

The Ministry of Basic and Secondary Education's (MoBSE) commitment to nurturing talents, addressing language proficiency issues, and promoting gender equity is acknowledged. The continuous efforts of MoBSE in fostering accessible, equitable, and quality education lay a foundation for the nation's educational advancement.

Call to Action for Continued Efforts in Education

As we conclude, a resounding call to action is extended to students, educators, policymakers, and stakeholders. Continued efforts are imperative to foster an inclusive and technologically enriched educational landscape in The Gambia. Collaborative endeavors, guided by the findings of this analysis and the commitment of MoBSE, will contribute to the nation's pursuit of educational equity, socio-economic development, and the empowerment of future generations.

In the spirit of collective responsibility, let us unite to propel The Gambia towards a future where education is a beacon of opportunity for all, regardless of geographic location or socio-economic background.

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Utilizing the Funds of Knowledge Approach to Teach Culturally and Linguistically Diverse Learners: Theory, Research, and Practice

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Introduction

Numerous scholars have explored the importance of aligning educational programs and curricula with the assets and needs of culturally and linguistically diverse (CLD) learners. Cho et al. (2019) defines culturally and linguistically diverse students as "learners who are part of an ethnic and/or language group considered to be different from that of the majority population" (p. 54). Sprott & Msengi (2019) contend that this population is comprised of "individuals or a group whose culture, language, and ethnicity are different from the dominant group" (p. 166). One important commonality among these definitions is that the term principally refers to those learners who vary from the White, middle-class, mainstream prototypical students in some form or fashion. This is particularly important since the majority of teachers in primary and secondary schools are White monolingual females and therefore "many White, middle-class…teachers assume that they do not have a particular language, culture, or history that is remarkable or particularly worth sharing" (Haddix, 2008, p. 261). Thus, because these educators see and experience their own cultural behaviors, references, values, etc. demonstrated and represented everywhere, they often are unaware of their own cultural identity and/or conclude that culture is uniquely something that "others" possess: "lack of cultural understanding reinforces Euro-American teachers' sense of 'us' and normal…and 'them' as abnormal…" (Florio-Ruane, 2001, p. 26). As a result, educator preparation "must begin by locating issues of multiculturalism and multilingualism *within* the experiences of white, monolingual…teachers and not outside them" (Haddix, 2008, p. 268; emphasis in original).

Additionally, other academics have highlighted the importance of familiarizing pre-service teachers with effective methods and approaches for teaching CLD as an essential component of educator preparation. For instance, Zhang-Wu (2017) specifies that culturally and linguistically response (CLR) pedagogy constitutes "an educational approach that takes CLD learners' diverse cultural and linguistic backgrounds into consideration in order to provide instruction that is responsive to the needs of students" (p. 34) and affirms that educators should focus their teaching on addressing students' linguistic and cultural assets and needs due to the symbiotic and synergistic nature of culture and language. Hadjioannou et al. (2016) remark that, due to the increasing diversity of students in primary and secondary classrooms, "the need to prepare mainstream classroom teachers to work with culturally and critically diverse learners is at a critical juncture" (p. 23) and that teacher preparation programs must do all they can to equip pre-service teachers with the skills and strategies necessary to teach these students effectively. Coelho et al. (2011) stress the importance of implementing such instruction with teacher candidates since "new teachers receive minimal preparation for teaching children whose linguistic, cultural, racial, religious, or social backgrounds are different from their own" (p. 56). Dunham et al. (2022) explain that culturally sustaining teachers should possess four essential characteristics, First, they should strive to become culturally competent by learning about the cultural and linguistic backgrounds of their students. Second, they should balance maintaining high standards for all students while simultaneously integrating their pupils' understandings, abilities, and skills into the classroom. Third, they should advance critical thinking by exposing students to important political and social issues affecting them, their communities, and their world. Finally, they should foster an inclusive environment in which all students feel valued, understood, and respected. Most importantly, Dunham et al. (2022) contend that culturally sustaining educators must endeavor to "…embrace a pluralistic approach that explicitly values multiple cultures and languages and decenters English dominant practices" (p. 682). In other words, rather than sustaining and upholding pedagogical conventions that promote White ideals and behaviors, such teachers must affirm the linguistic and cultural backgrounds of their students and defend their educational rights in the classroom. Coelho et al. (2011) agree with this perspective and maintain that "it is important to ensure that all students attain academic success regardless of their origin, language or individual characteristics" (p. 53).

Culturally Relevant, Responsive, Affirming, and Sustaining Pedagogies

When exploring research concerning the effective teaching of CLD learners, four interrelated terms often appear:

culturally relevant pedagogy, culturally responsive teaching, culturally affirming education, and culturally sustaining pedagogy. Although there are essential similarities between these terms in that they all strive to underscore the importance of adjusting and tailoring instruction to address the strengths and meet the needs of these students, there are also fundamental differences between them. Thus, it is crucial to briefly review the definitions of these terms in order to better understand their advantages and their limitations.

First, Ladson-Billings (1995) explains that an essential strength of culturally relevant pedagogy is that it "helps students to accept and affirm their cultural identity while developing critical perspectives that challenge inequities that schools (and other institutions) perpetuate" (p. 469) and asserts that such teaching "must provide a way for students to maintain their cultural integrity while succeeding academically" (p. 476). The term *relevancy* implies a strong connection between two entities; within the realm of education, this word implies learning that is "personally and/or contextually salient" (Joordens, Kapoor, & Hofman, 2019, 231-232) for students. Thus, culturally relevant pedagogy seeks to align a given course, curriculum, program, etc. with the abilities, expertise, knowledge, skills, etc. of students.

Second, Gay (2002) defines culturally responsive teaching as" using the cultural characteristics, experiences, and perspectives of ethnically diverse students as conduits for teaching them more effectively" (p. 106). Vavrus (2008) contends that such teaching "acknowledges and infuses the culture of [marginalized] students into the school curriculum and makes meaningful connections with community cultures" (p. 49) while also "using meaningful cultural connections to convey academic and social knowledge and attitudes" (p. 49). The word *responsive* tends to connote that a given entity is flexible and able to be adapted to its targeted audience; thus, culturally responsive pedagogy conceivably consists of adapting one's teaching to the capabilities, knowledge, proficiencies, etc. of one's students.

Third, Allen et al. (2013) clarify that culturally affirming education "is committed to the positive self-concept and racial identity development of students by honoring the legacy, and historical and contemporary contributions of their racial groups" (p. 124) so that "one's background, culture and experiences are viewed with high regard and esteem" (p. 124). In other words, one of the essential goals of this style of teaching is to facilitate and promote minoritized students' understanding of who they are, their past heritage, and their future legacy. Williams et al. (2022) confirm that culturally affirming education consists of "a culturally engaging environment that [is] humanizing and validating…" (p. 1075) for students from minoritized populations that focuses on "centering [their] personal experiences within the educational enterprise" (p. 1075). Thus, educators who align with this pedagogy endeavor to substantiate and incorporate the cultural and linguistic backgrounds, histories, and trajectories of their students in a supportive and empathetic environment.

Lastly, Paris (2012) argues that, although the terms culturally relevant pedagogy and culturally responsive teaching have played a pivotal role in helping educators better understand, value, and appreciate the cultural and linguistic assets that students from marginalized populations possess, these terms may not necessarily be adequately suited to advance the political and social action necessary to establish and maintain a truly plurilingual and pluricultural society. In their place, Paris (2012) proposes the term *culturally sustaining pedagogy* and states that such instruction "requires that [our teaching] support young people in sustaining the cultural and linguistic competence of their communities while simultaneously offering access to dominant cultural competence" (p. 95). Paris & Alim (2017) maintain that culturally sustaining pedagogy "seeks to perpetuate and foster – to sustain – linguistic, literate, and cultural pluralism as part of schooling for positive social transformation" (p. 1). The term *sustain* often connotes the simultaneous preservation and advancement of one or more aspects of a person's identity or position. Consequently, educators should not simply ensure that instruction is relevant to learners' backgrounds or that it responds to students' learning aims and needs; instead, such teaching should bolster their linguistic and cultural identities while also promoting their endeavors to question and challenge those systemic structures that maintain the educational, political, and social status quo.

Despite the commonalities and distinctions between these three terms, they nevertheless emphasize the necessity of considering CLD learners' backgrounds when planning and delivering instruction. First, lessons must be culturally relevant so that students grasp the connections between the content and their linguistic/cultural identities. Second, lessons should be culturally responsive to support the relevancy of the content to their families and communities. Third lessons need to be culturally affirming so that pupils' linguistic and cultural ancestry and legacies are appreciated, respected, and valued. Lastly, lessons ought to also be culturally sustaining so that their abilities, expertise, skills, talents, etc. form the basis of their educational pursuits.

The Funds of Knowledge Approach

Theory

Although a number of strategies and techniques have been explored over the years to make education more linguistically and culturally relevant, responsive, affirming, and sustaining, one effective means for doing so that has gained traction over the last several decades is the funds of knowledge approach. González et al. (2005) define funds of knowledge are "…historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual functioning and well-being" (p. 72). In a similar vein, Esteban-Guitart (2016) explains that funds of knowledge constitute a "repertoire of cultural and intellectual resources…that households accumulate and use to maintain their welfare and quality of life" (p. 81) and contends that "…abundant resources can be found in any household regardless of the ethnic, linguistic, or sociocultural background of the people living there" (p. 39). The approach began to initially began to gain traction in the late 1980s and early 1990s through the work of Dr. Carlos Vélez-Ibáñez and Dr. James Greenberg (e.g., Vélez-Ibáñez & Greenberg, 1989; Vélez-Ibáñez & Greenberg, 1992) and was subsequently extended and expanded predominately by such scholars as Dr. Norma González and Dr. Luis Moll, among others (i.e., Gonzalez et al., 1993; Gonzalez et al., 2001; Moll et al, 1992). The approach was primarily intended to respond to the deficit thinking (Valenzuela, 1999; Valencia, 2010) typically associated with students from minoritized populations at the time. In essence, it was commonly thought that the achievement gap between White students and non-White students was due in large measure to the linguistic and cultural socialization they received in their home communities which deprived them of certain academic experiences and understandings that they were expected to have/know. This misguided perspective concerning minority students was a logical but fallible conclusion due to the inaccurate and inequitable comparison of the cultural and linguistic backgrounds of White students to those of their non-White counterparts. Consequently, instead of conceptualizing minoritized learners as lacking specific expertise and proficiencies, the funds of knowledge approach produced a substantial paradigm shift in the educational realm in that they were now considered from a strengths-based position (Bartlett & García, 2011). Johnson and Johnson (2016) concur with this perspective and affirm that the approach assists in "…leveraging the historically accumulated sociocultural biases that continue to drive practices in mainstream American classrooms" (p. 117).

González et al. (1994) explain that the funds of knowledge approach consisted of a partnership between primary teachers and university scholars and that consisted of an investigative project in which teachers visited the homes of several students in their classes and conducted ethnographic research in order to document and understand the funds of knowledge possessed and demonstrated by these students' funds of knowledge which were subsequently incorporated into their lessons. The project also fostered collaboration between educators and academics through after-school labs during which teachers shared the results of their home visits and designed future lessons for these students. Instructors consistently commented on how the project helped them conceptualize culture beyond the stereotypical components of food, festivals, folklore, etc. and guided them in truly understanding the nature of the linguistic and cultural assets of these students and the households in which they lived. In a nutshell, one of the more fundamental outcomes of this investigative enterprise is that "teachers have come to view their students as competent participants in households rich in cognitive resources, and have consequently raised their expectations of their students' abilities" (p. 5).

Research

Numerous researchers have explored the role of integrating the funds of knowledge approach into a variety of educational contexts. The intention here is not to provide a comprehensive or systematic review of the related research in this area but to highlight several important investigations concerning this domain in a variety of educational settings.

Individual Studies

A number of scholars have empirically investigated the role that the funds of knowledge approach plays in CLD learners' education. For example, Moje et al. (2004) conducted a research study intended to examine the role of disciplinary knowledge and discourses in the education of 12-15-year-old Latinx students attending an urban school in the northcentral United States and the contribution of this knowledge/discourse to the literacy practices demonstrated by these students in the science classroom. The goal of the investigation was to identify the funds of knowledge possessed by these students, the discourse circles in which they were circumscribed, and the ways in which students drew on these understandings when reading science texts. Findings from the study showed that, while students drew predominantly from the funds of knowledge concerning a variety of areas that their families exhibited, they also utilized funds of knowledge obtained from experiences in other social and peer communities as well as in various popular culture outlets due to the fact that they inhabited multiple social circles in their personal and academic worlds. Based on these results, Moje et al. (2004) surmise that "teachers, researchers, and curriculum or text developers [should] develop curricula and texts that draw from and respond to the many different knowledges, Discourses, and texts that young people bring to school" (p. 65).

Johnson & Johnson (2016) summarize a study they completed in which they documented the incorporation of English learners' funds of knowledge into content-area lessons they taught to their classmates. The goal of the investigation was to help students identify both out-of-school and in-school funds of knowledge that may be relevant when designing and delivering a language arts lesson and a science lesson to their primary-level student colleagues. Participants in the study were two elementary-age English learners whose first language was Spanish. Results from the investigation indicate that both students incorporate both personal and academic funds of knowledge in their lessons, which not only demonstrated their own expertise in various areas but also contributed to the relevancy of the lesson for their classmates. Teaching the lessons also had a positive effect on participants' views of themselves and their overall motivation for learning. The authors contend that incorporating students' funds of knowledge into instruction "…is a powerful step towards leveling the historically accumulated sociocultural biases that continue to drive practices in mainstream American classrooms" (p. 117). In other words, the approach challenges the deficit perspective from which students from minoritized populations have traditionally been viewed by affirming and valuing the cultural and linguistic assets these students possess.

Kiyama (2010) carried out a research study in order to uncover the contribution of the funds of knowledge produced and disseminated by the families of Mexican American college students to these learners' perspectives on higher education. The objective of the investigation was to determine the funds of knowledge of these households and specify the role they play in learners' views in regards to their conceptualizations of college. Participants in the study included first-generation college students enrolled in a community outreach program who both identified as Mexican American and came from lower socioeconomic classes. Findings from the study illustrate that learners' knowledge in regards to college emanated not only from their families but also from a variety of interpersonal connections with others who had either attended or graduated from college and consisted of both motivations and aspirations for attending college but also the identification of potential obstacles that may impede students from successfully completing their undergraduate studies. These results suggest that the funds of knowledge demonstrated by families of Mexican American first-year college students are not acknowledged or appreciated, "parents may not realize their own resources, may not develop the confidence to help their children with educational processes, and may fail to tap into their own experiences to help their children succeed" (p. 351).

Literature Reviews

In addition to individual studies, several scholars have also reviewed and commented on the current state of the field in regards to the funds of knowledge approach. For instance, Hogg (2011) explores over fifty scholarly texts in which the approach was employed in a variety of contexts and identified a number of interesting patterns that emerged from her analysis. First, the majority of the studies were completed within the United States, and relatively few publications examined the utilization of the approach in international venues. Second, the studies included in the review took place in various settings that were both educational and non-educational in nature. Third, initial publications focused on the relevancy of the approach to building students' literacy, while subsequent research explored the connections between the approach and other larger educational and societal issues. Fourth, the authors that completed initial work in this area (i.e., Norma González, James Greenberg Luis Moll, Carlos Vélez-Ibáñez) initially conceptualized funds of knowledge as areas relating specifically to households that serve to promote their existence and advance their cultural wealth. However, succeeding academics contend that funds of knowledge involve additional areas and communities beyond merely households, including (but not limited to) peer social groups and larger interpersonal and educational entities. Additionally, while early scholars in this area centered on the social nature of funds of knowledge, intellectuals in later times emphasized the applicability of these cultural and linguistic resources at the individual level, somewhat akin to Esteban-Guitart and Moll's (2014) identification of funds of identity, which they define as ""historically accumulated, culturally developed, and socially distributed resources that are essential for people's self-definition, self-expression, and self-understanding" (p. 37). In other words, funds of knowledge are inherently social in origin, possessed and exhibited by social groups which subsequently become transformed into funds of identity when people subsequently incorporate them into their character and see them as essential characteristics that constitute their own self. Fifth, while many academics have viewed funds of knowledge in positive terms, scholars such as Zipin (2009) argue that certain funds of knowledge may be considered "dark" in relation to experiences that relate to larger educational, political, and social ills but that, rather than being ignored, the expertise that emerges from such experiences should be acknowledged and incorporated into curricula and programs just as "lighter" funds of knowledge not associated with certain emotional, physical, or psychological trauma. In this sense, problems affecting students' out-of-school lives should be recognized and managed so that students not see the relevancy of educational outcomes to their personal lives but are also equipped with the strategies and techniques necessary to process and find solutions for these dilemmas. Lastly, the field has experienced some discord in regards to which audiences can legitimately possess and disseminate funds of knowledge. Initially, it was believed that funds of knowledge were connected uniquely to students' out-of-school abilities and skills, but later research has enlarged this view to include not only in-school aptitudes and proficiencies that learners develop within school but also personnel that contribute to these scholastic resources (e.g., educators, administrators, counselors). Ultimately, despite the divergent visualizations of the approach that these and other scholars have promulgated, the power of the funds of knowledge framework is that it "challenge[s] teachers to reconsider their conceptualization of knowing their students" (Hogg, 2011, p. 673) by encouraging educators to truly understand their students in comprehensive and holistic ways.

Maitra (2017) outlines a number of studies that have been conducted within the realm of funds of knowledge in five principal areas: the identification and documentation of the funds of knowledge exhibited by members of various social circles and the contribution of this knowledge to students' education, the integration of students' linguistic funds of knowledge into educational curricula, the relevancy of learners' funds of knowledge to their academic and literacy skills in the mathematics classroom, the importance of providing students with the necessary time and space to share their personal and academic biographies and establishing connections between these stories and school learning, and the pertinence of a given community's shared funds of knowledge to the literacy practices in which members of the community practice. After furnishing an overview of numerous studies in these five areas, Maitra (2017) remarks that the funds of knowledge approach "…can be a beneficial tool for culturally diverse… students…" (p. 99) because it centers their linguistic and cultural assets as the foundation of instruction and "…offers…fantastic potential to connect students' home environments with their academic education" (p. 100) since it not only integrates their expertise, proficiencies, skills, etc. into the classroom while also showing them the applicability of their learning to the outside world.

Additionally, Moll (2019) reviewed four studies conducted in Australia, New Zealand, Spain, and Uganda in which scholars implemented the approach with students from minoritized populations in these locations in order to address the educational inequities experienced by these learners while also centering instruction on the linguistic and cultural assets of these students. In the first study, scholars worked with preschool students to identify the funds of knowledge families of these students inculcated and transmitted to them before they entered school and discovered that learners utilized these funds of knowledge as emerging theories to better understand their experiences and the world around them. In the second study, investigators employed a variety of activities designed to help families of immigrant students living in Spain document their funds of knowledge which were subsequently used to support their developing understandings of themselves as they negotiated their cultural and linguistic identities. In the third study, the funds of knowledge of students from economically-disadvantaged neighborhoods were integrated into schools in order to help them establish connections between their lives in school and their lives outside of school. In the fourth and final study, researchers sought to better understand the role of school in child-headed households in which one or both parents died from HIV and/or AIDS and found that the school functioned as an essential entity to validating these students' funds of knowledge but also provided them with economic and social resources to support themselves and their families. In the third study, Moll (2019) concludes that the ultimate outcome of these projects was to view "…families and students as resourceful…" (p. 137) and to "…help educators arrange environments that are academically sound and strongly oriented to building on such resources for learning" (p. 137). In other words, these studies demonstrated that employing the approach with these students supported them in achieving high academic standards and also guided teachers in perceiving these students from an asset-based perspective.

The publications highlighted above, whether they be individual studies or literature reviews, highlight the large number of academic, researchers, and scholars across multiple contexts who contend that the funds of knowledge approach is one viable and effective means for understanding the "whole" student through the validation and integration of minoritized students' cultural and linguistic strengths into educational programs and curricula and centering these learners' experiences in order to promote education that is culturally relevant, responsive, affirming, and sustaining.

Practice

Numerous scholars have underscored specific methods and practices for incorporating students' funds of knowledge into a variety of educational settings. As in the previous section, the purpose here is not to provide an exhaustive or comprehensive review of all publications in this area but merely highlight several studies which have done so successfully with various student populations. For example, Di Stefano (2017) outlines two procedures she utilized in her first-grade dual language immersion (DLI) Spanish/English classroom to help her more effectively identify her students' funds of knowledge while also supporting their awareness and understanding of their own linguistic and cultural assets. The first technique was comprised of the culture bag activity in which students selected items from home that they felt best represented their cultural identity, placed these items in a paper bag, brought the items to class, and shared the items with their classmates. The teacher participating in Di Stefano's (2017) study initially found that students demonstrated artifacts which largely represented mainstream American culture. In order to counter this hegemony of American products and values and also guide students in reframing their Latinx heritage, she then shared examples of items and experiences that represent her own cultural identity. After asking students to repeat the activity, the author found that students brought considerably more objects that represented their Latinx identity. In addition to the cultural bags, parents and community members were invited to her class to share various activities and traditions that figure prominently in Latinx popular culture, including arts and crafts, cooking, games, and music. These activities not only extended students' perceptions of other cultures but also created and established a strong connection between school and community. Di Stefano (2017) affirms that such activities can "socially transform the classroom environment and have a long-lasting effect on…students, who can recognize that their heritage experiences are valued in both their school and home settings" (p. 48) as a way to bridge students' home and school communities.

Newman (2012) identified a method for facilitating student writing through the use of mentor texts, which are "those books, stories, poems, essays, and other writings that we come back to over and over again" (p. 25). Utilizing such texts as guides for students' writing highlights the importance of "using students' funds of knowledge and individual language to empower them to express themselves, to tell their stories, and to become lifelong writers and readers" (p. 25) which serve to not only affirm and substantiate learners' identities but also promote their literacy skills. In her study, students read a variety of publications written by Rene Saldaña and Sandra Cisneros as exemplars to frame their own writing, which afforded them opportunities to identify and promote their linguistic and cultural funds of knowledge when creating their own texts. These texts were chosen to demonstrate not only the universality of childhood experiences but also accentuate the unique qualities of childhood encountered by Latinx students. After reading these texts, learners participated in a variety of activities designed to help them think more deeply about the issues explored in the documents and also determine particular stylistic techniques employed by the writers, including writing territories, image palettes, and cubing. After engaging in these tasks, Newman (2012) observed that her young writers not only improved but incorporated numerous autobiographical details relating to their cultural and linguistic identities, thus crystallizing her conviction that "young adolescents have home-based language and home-based learning experiences that can be relied upon to generate powerful stories" (p. 30), which educators are strongly encouraged to be mindful of when creating and implementing activities in the writing classroom.

Dworin (2006) implemented a writing project with fourth-grade students in a bilingual classroom in which learners deployed their linguistic funds of knowledge to explore their familial biographies. Similar to the pedagogical intervention explored in Newman (2012), the author utilized two stories from Lulu Delacre's *Cuentos con sazón/Salsa Stories* as mentor texts to familiarize them with content that would likely resonate with their own life experiences in terms of content but also exposed them to bilingual texts in both Spanish and English and provided them with examples of ways to combine both languages when writing in terms of form. After reading the stories, students were encouraged to document, collect, and bring stories from their own families with them to school. They were assembled into groups of four to five learners, with each group providing members feedback on their writing in regards to both form and content. Students initially wrote their family stories in English and then subsequently worked to translate these stories into Spanish; these stories were eventually published as two books, one in each language. Among other benefits, the project helped acquaint learners with their familiar heritage, supported them in discovering important aspects of their cultural and linguistic identities, and encouraged them to understand the relevancy of their out-of-school abilities and intelligences to their in-school learning. The project ultimately sustained and reinforced their bilingual and biliteracy skills by clearly demonstrating that "biliteracy is an aspect of culturally relevant teaching that can expand learning possibilities by building upon the languages and cultural identities of Latino students" (Dworin, 2006, p. 511). Thus, incorporating minoritized pupils' linguistic funds of knowledge into academic programs and curricula is one consequential way to ensure that these learners receive a culturally affirming, relevant, responsive, and sustaining education.

Street (2005) outlines a cognate project in which students in his urban secondary classroom utilized their personal experiences and competencies when completing class writing assignments. The intention of the project was to help students find their voices in their own writing via the exploration and examination of specific themes and topics that were of interest and relevancy to them. Consequently, the curricular innovation proposed by the author (namely, the "Funds of Knowledge Writing Project") was intended to not only substantiate these learners' funds of knowledge but also empower them to identify and consider subjects that were of significant consequence for them while simultaneously providing the author with multiple opportunities to better understand and appreciate his students' identities. Throughout the project, Street (2005) found that educational roles had progressively reversed in that his students became the teachers and he became the learner, a situation which ultimately led to a more democratic classroom in which authority and power were shared among everyone. As a result, the author was more familiar with learners' strengths and assets and also with the successes and challenges they faced in their academic and personal lives, leading to the establishment of stronger and deeper connections with his students. One of the more important lessons that resulted from the project is that "tapping our students' funds of knowledge…serve as an important educational tool that moves us toward the ideal of better connecting with the lived experiences of our students…" (p. 24).

Finally, Riojas-Cortez (2001) describes an investigation conducted in a preschool bilingual classroom in which she observed students during social playtimes and documented examples of familial funds of knowledge that they exhibited through their play. The purpose of the study was to better understand the backgrounds of the households in which these learners were being socialized so that their cultural identities could be recognized and appreciated. The study was also intended to move beyond a surface-level view of culture demonstrated merely through artifacts (i.e., flags, food) towards a more comprehensive perspective on culture displayed via specific behaviors representing important beliefs and values possessed by members of the students' cultural community. In furtherance of these goals, the author conducted a microethnographic study during which, as preschool-age learners enrolled in a two-way bilingual classroom engaged in sociodramatic play, she recorded the funds of knowledge these learners demonstrated through their interactions with their classmates along with interviews with the children's parents. Her analysis revealed that students manifested evidence of twelve categories of funds of knowledge, including (but not limited to) beliefs/values, education, household chores, language, and traditions. This study shows not only the interdependent nature of play and culture but also offers a viable way for educators to validate the linguistic and funds of knowledge possessed and displayed by their students as part of a “culturally reflective curriculum” (p. 39) in which students’ understandings and experiences are recognized and supported.

The range of projects and student populations outlined in these studies demonstrate various ways in which learners’ funds of knowledge can be identified, documented, and appreciated in a wide range of academic contexts and settings, from cultural bags and popular culture to writing to sociodramatic play. The overarching goal of these studies was to acknowledge and validate the cultural and linguistic funds of knowledge of pupils from marginalized groups whose expertise, aptitudes, and proficiencies have traditionally not been recognized or valued in the educational enterprise.

Conclusion

As primary, secondary, and tertiary classrooms become more diverse linguistically and culturally, it is essential that educators respond to this situation by identifying and valuing the funds of knowledge possessed and exhibited by these students. The purpose of this chapter was to highlight fundamental characteristics of culturally and linguistically diverse (CLD) learners and substantiate the importance of providing them with an education that is culturally affirming, relevant, responsive, and sustaining by not only incorporating their assets and strengths into educational programs but also centering their aptitudes, competencies, and resources as the foundation of such curricula. The chapter then outlined a legitimate yet cogent framework for doing so, namely the funds of knowledge approach by reviewing various theoretical principles that undergird the approach and by summarizing numerous publications which investigated the utilization of the approach into a variety of educational settings and which considered multiple projects designed to implement the approach in assorted contexts. It is hoped that the chapter inspires teachers, administrators, and researchers alike to "break down barriers between home and school" (Street, 2005, 22) by showing minoritized students the relevancy of their cultural and linguistic assets and strengths to the educational enterprise in order to help both educators and scholars strive to establish and implement educational policies and practices that are equitable and just for all students.

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The intersection of technology and education exerts a profound and far-reaching influence on societies and learning environments across the world. ***Current Academic Studies in Technology and Education 2023*** is the latest in a series of texts published annually from selected papers invited by the editors. The present edition consists of contributing international authors from Georgia, Türkiye, the United States of America, and Uzbekistan. All submissions are reviewed by at least two international reviewers.

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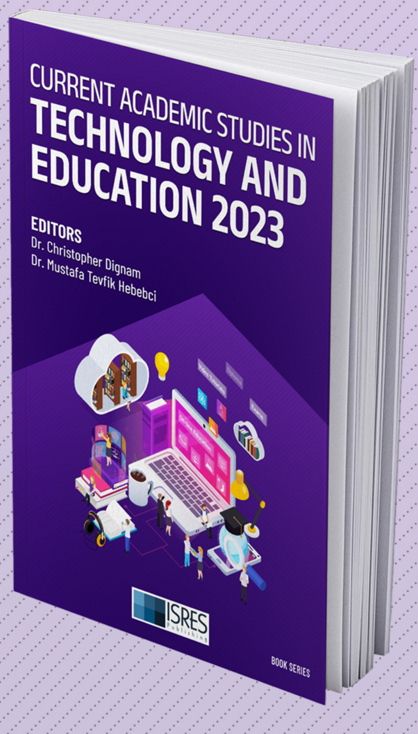

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