EXPLORING 21st CENTURY LEARNING IN VIRGINIA SECONDARY SCHOOL TECHNOLOGY AND ENGINEERING CLASSROOMS: A HERMENEUTIC PHENOMENOLOGICAL STUDY

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Abstract

The purpose of this phenomenological study was to examine how integrative STEM teachers utilize the *Standards for Technological and Engineering Literacy* (STEL) to foster and assess 21st-century learning in technology and engineering classes at multiple Virginia public secondary schools. The theory guiding this study was Kolb's experiential learning theory, which integrates nine learning theories into an innovative cyclical learning process that is like the engineering design loop. This hermeneutic phenomenology included 15 Virginia technology and engineering schoolteachers (Grades 6-12) who purposefully taught multiple academic disciplines and utilized the eight practices of the STEL in the context of their curriculum to foster 21st-century learning. Data collection included individual interviews, journal prompts, and physical artifacts (lesson plans, assessment tools, etc.). Data were entered into the Delve data analysis software and were analyzed using Van Manen's hermeneutic phenomenological theory for common themes regarding the fostering and assessment of 21st-century literacy. The themes extracted from the data included measuring 21st-century learning, developing 21st-century curriculum, and the eight practices of technology and engineering educators: creativity, collaboration, communication, critical thinking, optimism, attention to ethics, systems thinking, and making and doing. The findings indicated that integrative STEM methodology, multidisciplinary instruction, and the eight practices of the STEL fostered 21st-century learning. This study's significance was to add to the available literature on integrative STEM education and the STEL fostering 21st-century learning.

Keywords: 21st-century learning, integrative STEM education, technology and engineering education, creativity, *Standards for Technical and Engineering Literacy* (STEL), industrial revolution 4.0, hermeneutic phenomenology

Copyright Page

Dedication

I dedicate this dissertation to the Holy Trinity. I thank my Lord and Savior, Jesus Christ, for redeeming me. I thank the Holy Spirit for guiding me through my educational journey. I thank God, who has blessed me in abundance and called me to be an educator.

I dedicate this to my wife, my best friend, and the love of my life, who inspires and encourages me to become a better man daily.

To my children, may the Holy Spirit guide you to find and use all your God-given talents.

To my parents, who raised me in a Christian household and supported me in every season of my life.

To my sister, thanks for being the best sibling one could ask for.

To the memory of my paternal grandmother, who always believed in my academic abilities and encouraged me along my educational journey.

I sincerely thank all my family members who have been a source of continual encouragement through my doctoral journey.

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List of Abbreviations

Career and Technical Education (CTE)

Experiential Learning Theory (ELT)

International Technology and Engineering Educators Association (ITEEA)

National Academy of Engineering (NAE)

National Education Association (NEA)

Partnership for 21st Century Learning (P21)

Pedagogical Content Knowledge (PCK)

Programme of International Student Assessment (PISA)

Project or Problem-Based Learning (PBL)

Standards of Learning Assessment (SOL)

Science, Technology, Engineering, and Mathematics (STEM)

Science, Technology, Engineering, Art, and Mathematics (STEAM)

Standards for Technological and Engineering Literacy (STEL)

Technology and Engineering (T&E)

Technology, Entertainment, Design Talk (TED Talk)

Technology, Science, Math (TSM)

Virginia Technology and Engineering Educators Association (VTEEA)

Workplace Readiness Skills (WRS)

CHAPTER ONE: INTRODUCTION

Overview

Freedom, liberty, and independence are the overarching principles that have defined the culture of the United States for two and a half centuries. Freedom allows every United States citizen to prosper physically, mentally, emotionally, financially, and spiritually. The culture of the United States depends heavily on its educational system, providing students liberty by equipping them with the skills and knowledge necessary to choose any postsecondary endeavor they desire. The global marketplace is in a constant state of innovation and expansion, creating a demand for workers who possess skills and abilities adept for the 21st century. Globalization has caused American educational stakeholders to revise compulsory education to include 21st-century learning skills.

Freedom, liberty, and independence not only influence the American government, but they also influence American education as well. Government leaders desire an independent constituent base, free to support themselves financially by ethical and self-sufficient means. Four separate industrial revolutions have resulted in the globalization of the world's economy. The United States educational system has been in perpetual stagnation for the second, third, and fourth industrial revolutions. The skills needed to have the freedom of occupational choice are vastly different now than a century ago. The world is currently in the fourth industrial revolution. The educational buzzwords and acronyms for 21st-century learning are science, technology, engineering, and math (STEM), science, technology, engineering, art, and math (STEAM), integrative science, technology, engineering, and math (integrative STEM), project-based learning, engineering design, interdisciplinary learning, transdisciplinary learning, multidisciplinary learning, 21st-century skills, soft skills, life skills, creativity, collaboration, critical thinking, communication, cultural and character education, (Bolden et al., 2020, Colton et al., 2020; ITEEA, 2020; Mullen, 2019; P21, 2022). This study explored teachers' experiences utilizing the *STEL*, experiential learning theory, and integrative STEM education methodology to educate a workforce with skills needed for independence, liberty, and freedom in the 21st century.

Background

The United States has witnessed accelerating change since its inception in the 18th century. Accelerated change is the theory that technology is changing exponentially, affecting cultural and social norms changes. Technological change has been documented and grouped into industrial revolutions. The first industrial revolution happened in the latter half of the eighteenth century and focused on mechanization and the invention of the steam engine. The second industrial revolution took place in the second half of the nineteenth century and focused on mass manufacturing and new energy sources such as electricity and oil. The third industrial revolution happened in the second half of the twentieth century and focused on digital electronics and nuclear energy. The fourth industrial revolution started around the start of the new millennium and focuses on the Internet of Things, which has brought about a globalized society (Becker, 2019: Schwab, 2017). This study aimed to understand teachers' experiences that adapted their teaching methods to meet the demands of accelerated change.

Historical Context

The primary means of employment in the United States 150 years ago were agrarian and manual manufacturing jobs that relied heavily on physical skills. Because of the dependence on manual labor, before World War II, only 2% of qualified students attended college (Lucas, 2016). Advances in robotics and automation have enhanced agricultural production and mass manufacturing. Physical labor employment still exists today but typically consists of entry-level low-wage jobs. High monetary compensation in the 21st century, desired and needed in a first-world country, depends on cognitive abilities and soft skills. Problem-solving, customer service, and technological and engineering literacy are in demand in the globalized workforce. The problem is that many public schools still prepared students for jobs prevalent in the 19th century. For students to learn 21st-century skills, teaching methodology must be adapted. Integrative STEM methodology offers the possibility to teach problem-solving while learning people skills and collaboration to create a more desirable worker in the 21st-century job market.

Industrial Revolution's Influence on Education

Technology results from meeting human needs or wants (ITEEA, 2020). Technology excels when there is collaboration between disciplines. An excellent example of this collaboration is the STEM acronym for science, technology, engineering, and mathematics. STEM innovations have produced four separate industrial revolutions. The first industrial revolution happened circa 1765, highlighted by the agricultural world's mechanization and the steam engine's invention. The first industrial revolution was driven by the need to clothe and feed people year-round. The second revolution, often considered the most critical industrial revolution, happened in 1870, highlighted by the utilization of new fuel sources of electricity, gas, and oil. The second industrial revolution introduced entrepreneurship, mass manufacturing, and the potential to prosper financially. The third industrial revolution started circa 1969, highlighted by the rise of electronics, computers, telecommunications, robots, and nuclear energy, and focused on making life more comfortable and convenient. The fourth industrial revolution is happening now and includes the expanding use of the internet, virtual reality, artificial intelligence, genetic engineering, and 3D printing (Pouspourika, 2020). The fourth industrial revolution is growing exponentially and focuses on the needs and wants of a diverse global population.

Standards for compulsory education began as the world shifted into the Second Industrial Revolution when the United States workforce demanded employees with skills, not just manual laborers. The Second Industrial Revolution required workers who were literate and could follow directions. Assembly lines and manufacturing emerged as the leading employers of the second industrial revolution. Workers did repetitive tasks using lower-order thinking skills. The framework to train workers for employment in the Second Industrial Revolution is still in place today.

The Third Industrial Revolution introduced digital electronics and focused on making life more convenient. A college education was needed for higher-compensation employment in designing and creating electronics. Assembly line jobs were still available; however, automation lessened the need for manual labor jobs. Financial prosperity was linked more to higher education in the Third Industrial Revolution than K-12 compulsory education.

The world is in the Fourth Industrial Revolution, also known as Industrial Revolution 4.0. Today, financial prosperity depends on learning how to work collaboratively on projects initiated by various structures of society and business (Anisimova et al., 2018). Today, consumers demand innovative goods that are functional, sustainable, usable, and serviceable (Chou, 2021). Business leaders desire workers who are efficient, collaborative, and creative (Carnevale et al., 2020). Rahmawati and Taylor (2019) state that multidisciplinary educational methodology empowers the direct instruction pedagogy of math and science disciplines to create globally competitive stakeholders. This study explored integrative STEM methodology as a way to prepare students to be competitive in the 21st-century economy.

The NEA's Committee of Ten

Public compulsory education in America started in the early 19th century. American education did not initially have a standardized curricular framework; some schools followed the Prussian model of education, which did not focus primarily on intellectual training (Rothbard, 1979), and some taught a classical education curriculum (Lucas, 2016). Today's educational model used mainly in American high schools includes four core subjects of language arts, social studies, mathematics, and science taught as isolated disciplines. This four-core framework was established in 1892 by the National Education Association's (NEA) Committee of Ten (Mackenzie, 1894). In 1892, the world was in the early years of the Second Industrial Revolution, when society shifted from an agrarian economy to an economy based on mass production. In 1892, slightly more than half the population had attended K-12 schools (Lucas, 2016). The primary goal of the education system in 1892 was to produce more competent, dependable workers who filled numerous manufacturing jobs. The results of the decisions of the Committee of Ten were astounding. The four-core model of education successfully trained a workforce to be literate and equipped each future worker with basic, lower-order thinking skills (remembering, understanding, and applying). Completing compulsory education created a financially competitive worker in the economy of the second industrial revolution. Workers and business owners in the United States prospered exponentially throughout the first half of the 20th century.

The Two Cultures and the Scientific Revolution

The framework established by the NEA created an educational landscape of separated, isolated disciplines. In 1959, C. P. Snow, a British novelist, presented at the annual Rede Lecture at the University of Cambridge. The title of Snow's lecture was The Theory of Two Cultures and the Scientific Revolution. Snow (1959) stated that Western society could be grouped into two "cultures," the sciences and the humanities. Snow explained that the two groups of intellectuals were vastly different, almost opposites in solving problems. Scientists are critical thinkers, while humanities scholars are creative and artistic. Snow (1959) also noted that these two cultural groups rarely worked together or communicated. Snow insisted that this lack of interaction is why many of the world's most challenging problems still needed to be solved.

Snow (1959) identified and detailed the silo approach in academia. The silo approach is the monodisciplinary method of teaching one academic discipline at a time, with no collaboration from another field. The silo approach of isolated disciplines is still widely used today. Snow noted that problem-solving required collaboration. Integrative STEM methodology is a collaborative, interdisciplinary way of teaching creative problem-solving.

Methodology of Integrative STEM Education

Integrative STEM education is broader than the four disciplines included in the acronym. Integrative STEM methodology is complimentary education that fosters higher-order thinking and learning from experiences of both the sciences and the humanities. Purposeful teaching of any discipline can be used in integrative STEM education. Integrative STEM and STEAM methodology are similar in many ways. STEAM education requires students to utilize the content learned in different disciplines and apply it to a real-world task (Daugherty, 2013). There is no separation between science and humanities or isolation between fields; collaboration is essential.

Interdisciplinary curricula like integrative STEM and STEAM education aim to teach students skills needed to be successful in the 21st century. A 21st-century education produces logical, analytical, rational, process-driven, aesthetic, interpretive, intuitive, and cultural students to view the problem from different discipline perspectives (Berry et al., 2021). There are two minor distinctions between integrative STEM and STEAM education. Integrative STEM methodology first stresses discipline collaboration, student collaboration, and design-based teaching. Integrative STEM methodology encourages the learner to innovate and solve a human want or need better, whereas STEAM simply asks the learner to complete a real-world task. Secondly, STEAM education currently has no educational governing body. Integrative STEM is governed by the International Technology and Engineering Educators Association (ITEEA) and has an up-to-date educational framework, the *STEL* (ITEEA, 2020). For these two reasons, integrative STEM methodology was used for this study.

Social Context

Higher education teacher training programs for technology, engineering, and STEM teachers implement learning taxonomies where the optimal goal is to foster higher-order thinking. Most learning taxonomies are a derivative of Bloom's taxonomy (1956), which uses a hierarchal learning pyramid with six levels of learning. Higher-order thinking is the application of knowledge with skill. Bloom (1956) and Anderson et al. (2001) designate that the highest level of learning is being able to create.

The Fourth Industrial Revolution has provided everyone with an internet connection and the capability to access information in seconds. To prosper in the 21st century, workers must apply readily available knowledge to skill(s). There must be a paradigm shift in education to create a skillful and knowledgeable workforce. Integrative STEM methodology can optimize higher-order thinking with collaborative instruction.

Changing teaching methods to foster 21st-century skills will result in revised assessments. In the current setup, isolated disciplines rely primarily on standardized tests or large-scale projects. 21st-century learning will require a diversification of both formative and summative evaluations. The national professional organizations for the four core disciplines (mathematics, social studies, English, and science) all call for teacher training programs to train future teachers to teach a 21st-century curriculum (NCTM, 2022; NCSS, 2022; NCTE, 2022; NSTA, 2022). A 21st-century curriculum will teach literacy and skills needed in the fourth industrial revolution and require differentiated assessments.

Theoretical Context

Twenty-first-century instruction in technology and engineering classrooms involves teachers with pedagogical content knowledge (PCK) (Shulman, 1986) that focuses heavily on making and doing (ITEEA, 2020). 21st-century learning requires students to be experiential learners (Kolb, 1984). Experiential learning is when students use the knowledge gained from their experiences to solve a problem in education or the workforce. 21st-century learning is much more than knowledge acquisition. Students learn more than content knowledge; 21st-century learners become technologically and digitally literate. 21st-century learners develop values, learn ethics, become culturally sensitive, and learn life and soft skills. Most importantly, 21st-century learners become higher-order thinkers and apply the knowledge and values learned. Application of knowledge occurs by collaborating with others and using critical thinking and creativity to solve real-world problems.

The framework established by the NEA in 1893 created an academic caste system. This caste system has dictated the four core compulsory subjects of language arts, mathematics, science, and social studies are the most critical areas of education. The non-core disciplines are often called electives, encore classes, or special classes because students elect if they want to enroll in these classes. Social mobility is the term used for changing status in a caste system.

Academic disciplines have no social mobility in 19th-century education because of their isolated silo approaches to instruction; the four core classes are viewed as more important because they are required. 21st-century education is quite different, and 21st-century employers desire workers with new skills (Carnevale et al., 2020). The basic knowledge taught by the four core subjects is now readily and easily accessible to anyone with an internet connection (Khan, 2012). 21st-century learning requires equity and social mobility of all disciplines to allow 21st-century learning to occur correctly.

Teachers teach from experience and mimic the teaching methods used by their favorite teachers (Oleson & Hora, 2014). Teachers continue to train with antiquated methods of the 19th century because that is their experience and the way their favorite teacher taught them. More importantly, teaching lower-order thinking skills has shown consistent improvement over time. More people are literate and attending higher education than ever (Lucas, 2016). However, the focus of education is stuck in the Second Industrial Revolution to provide a literate workforce. The No Child Left Behind legislation only examines language arts and mathematics in America (NCLB, 2002). Education stakeholders need to address the needs of the fourth industrial revolution. Teacher training programs do not teach 21st-century skills (critical thinking, communication, creativity, and collaboration) (Colton et al., 2020). This study explored teachers' experiences teaching 21st-century curricula, and the skills needed to be prosperous and globally competitive.

Problem Statement

The problem is that American K-12 public schools have antiquated curricula that do not adequately prepare students for life in the 21st century. Not only do American public schools have lackluster performance on international competency tests such as the Programme of

International Student Assessment (PISA) tests, but the methods of PISA assessment using multiple-choice questions are antiquated as well (DeSilver, 2020; Zhao, 2020). 21st Century employers desire workers with different skill sets: workers that can utilize higher-order thinking, are technologically and digitally literate, possess a sense of ethics, values, and life skills, and can collaborate with others to problem-solve (Carnevale et al., 2020). Lacking is a widely accepted and mandated methodology to purposefully teach 21st-century curricula to United States K-12 public school students. The *STELs* (ITEEA, 2020) provide an up-to-date framework for 21st-century learning. Integrative STEM education methodology utilizes design-based, purposeful instruction of multiple disciplines to foster higher-order thinking and adequately teach the *STELs*. This study is needed to empirically explore the experiences of technology and engineering teachers using the *STEL* and integrative STEM methodology to equip students for postsecondary life in the 21st century.

Purpose Statement

The purpose of this hermeneutical phenomenological study was to understand the experiences of Virginia public secondary technology and engineering teachers on how they fostered 21st-century learning using the integrative STEM methodology in their classrooms. For this study, 21st-century learning is defined as the eight practices of the *Standards of Technological Literacy*: communication, collaboration, critical thinking, making and doing, attention to ethics, creativity, systems thinking, and optimism (ITEEA, 2020).

Significance of the Study

This hermeneutical phenomenological study has theoretical, empirical, and practical significance. Theoretically speaking, an innovative learning theory is being used to innovate learning. Kolb's (1984) experiential learning theory combines the works of nine scholarly theorists. Empirically, this study seeks to expound on the link between 21st-century learning and STEM instruction (Stehle & Peters-Burton, 2019). This study's practical significance is a better understanding of how schools can produce human capital (Sima et al., 2020) and provide the global economy with a workforce with workplace readiness skills (Carnevale et al., 2020). Exploring the experiences of technology and engineering teachers should expound upon the methods of educational innovation and 21st-century learning.

Theoretical Significance

21st-century learning requires experiential learning (Kolb, 1984), meaning students must learn by direct experience by doing. Kolb's experiential learning theory is an innovative learning theory that is inspired by the works of Dewey (1915; 1916), Follet (1918), James (1890), Freire (1970; 1973), Vygotsky (1978), Jung (1969), Piaget (1929; 1953), Lewin (1939), and Rogers (1959). Experiential learners use every interaction, situation, and environment to become literate. To become literate with 21st-century skills, students must use the knowledge gained experientially to solve a problem in education or the workforce. While 21st-century pedagogical teaching and learning methods have been identified, educational stakeholders across disciplines still primarily use the Socrates method (asking students repeated questions and having them answer until correct) of instruction (Kesici & Çavuş, 2019). The *Standards of Technological Literacy* (ITEEA, 2023) provides a quality framework, and integrative STEM education offers the ability to teach the eight teaching practices needed for 21st-century learning.

Empirical Significance

Empirical research has identified methods to improve student learning. Active learning has improved student achievement (Kesici & Çavuş, 2019). Student-centered practices also improve students' learning and critical thinking skills (Gammons & Inge, 2017). Critical thinking, collaboration, creativity, and communication are the four essential competencies (the four Cs) that comprise 21st-century skills (Colton et al., 2020). Some countries have recently added two Cs to 21st-century skills to make six Cs, adding culture and character education (Nadiroh et al., 2021). *The Standards of Technological Literacy* go beyond the 6 Cs and define eight teaching practices necessary for 21st-century learning: communication, creativity, collaboration, critical thinking, attention to ethics, making and doing, systems thinking, and optimism (ITEEA, 2020). 21st-century learning utilizing integrative STEM methodology is a collaborative, active, hands-on, minds-on way to improve student learning.

Practical Significance

The primary reason 21st-century learning is significant to research deals with the antiquated methods of 19th-century learning that are currently used in most American public schools. The Socratic method is no longer optimal in education because anyone wanting to find an answer has a smartphone and a search engine in their pocket. Employers want workers who can apply readily available knowledge and problem-solve (Carnevale et al., 2020). A 21st-century learner can apply, analyze, evaluate, and create. The study's practical significance is to explore how integrative STEM teachers teach 21st-century curricula defined by the *STEL* and improve student-centered learning, improving how educational stakeholders foster and assess 21st-century learning.

Research Questions

A 2019 study empirically linked purposeful lesson planning to teach 21st-century skills to students in an inclusive STEM high school (Stehle & Peters-Burton, 2019). While the study connected the intentional instruction of 21st-century learning to STEM classes, the study did not clarify if integrative STEM methodology was used or inquired about the teachers' experiences teaching and assessing 21st-century skills. This study explored the perspectives and experiences of technology and engineering teachers who utilize integrative STEM methodology.

Technology and engineering educators possess different pedagogical content knowledge (PCK) than teachers from other disciplines. PCK is the concept Shulman (1986) developed that a teacher must have more than subject matter knowledge. PCK is the expertise and skills a teacher possesses to instruct students on applying the knowledge they learn in class. The following questions investigate the technology and engineering educators' PCK as they foster 21st-century learning.

Central Research Question

What are the experiences of Virginia Technology and Engineering Teachers using integrative STEM methodology to implement the *Standards for Technical and Engineering Literacy* and foster 21st-century learning?

Sub-Question One

What are the experiences of Virginia Technology and Engineering Teachers with assessing the *Standards for Technical and Engineering Literacy* resulting from integrative STEM instruction?

Sub-Question Two

How do Virginia Technology and Engineering teachers using integrative STEM methodology develop a 21st-century curriculum based on experiential learning theory and the *Standards for Technical and Engineering Literacy* frameworks?

Definitions

1. *21st Century Skills*- skills needed to be successful in the marketplace and be globally competitive in the 21st century (ITEEA, 2020; ISTE, 2022; Levy & Murnane, 2004; P21, 2022).
2. *Collaboration*- Identified in 21st-century learning as a needed digital and analog skill (ITEEA, 2020; ISTE, 2022; P21, 2022). Collaboration is working in groups to solve a problem.
3. *Communication*- Identified in 21st-century learning as a needed digital and analog skill (ITEEA, 2020; ISTE, 2022; P21, 2022). Communication is the process of articulating ideas and information to others.
4. *Creativity*- Identified in 21st -century learning as a needed digital and analog skill (ITEEA, 2020; ISTE, 2022; P21, 2022). Creativity has an individualist definition (Sawyer, 2011) and is the process of inventing (making completely new products/processes) and/or innovating (improving existing products/processes) (ITEEA, 2020). Creativity is the highest form of learning (Anderson et al., 2001; Bloom, 1956). Creativity also has a sociocultural definition, by which creativity is established and judged by a peer group (Sawyer, 2011). Rhodes (1961) simplified 40 prior definitions of creativity into the 4 Ps of creativity: person, process, press, and product.
5. *Critical Thinking*- Identified in 21st-century learning as a needed digital and analog skill (ITEEA, 2020; ISTE, 2022; P21, 2022). Critical thinking, defined by Bloom (1956) and Anderson et al. (2001), is the ability to evaluate, synthesize, and analyze, essentially higher-order thinking.

6. *Design-based learning- is* a learning methodology that requires students to apply theoretical knowledge to design a solution for a human want or need (Sanders & Wells, 2010).
7. *Education 4.0-* Education during the fourth industrial revolution as society is constantly connected by the internet.
8. *Education 5.0-* Education in the fifth industrial revolution as society incorporates more artificial intelligence (AI) and human-computer communication.
9. *Educational Technology-* One of the four ways "technology" can be defined. Refers to using manmade tools and devices (primarily digital electronics) to enhance and/or instruct (Reed, 2018).
10. *Engineering Grand Challenges-* fourteen world problems that are currently unsolved. Examples include providing energy from fusion, reverse engineering the brain, and providing clean drinking water to the world's population (NAE, 2022).
11. *Experiential Learning Theory-* The theory created by David Kolb defines learning as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience" (Kolb 1984, p. 41).
12. *Global Competitiveness-* being in the upper echelon of educational preparedness for work in a global society (Robinson, 2017).
13. *Higher-order thinking-* pertaining to hierarchal learning taxonomy as the pinnacle of education. Bloom's taxonomy contains evaluation/creativity as the highest order of thinking (Anderson et al., 2001; Bloom, 1956).

14. *Industrial Arts*- known before 1904 as manual arts. The name officially changed to Technology Education in 1985 (Dugger, 2013). Pertains to the study of technology, which is the man-made world.
15. *Industrial Revolution 4.0* is the fourth global industrial revolution that utilizes cloud computing, augmented reality, digital networks, analytics, and autonomous robots (Shahroom & Hussin, 2018).
16. *Information Technology*- One of the four ways "technology" can be defined. Refers to computer programming, computer networking, and digital communication (Reed, 2018).
17. *Integrative STEM education*- "...technological/engineering design-based learning approaches that intentionally integrate content and process of science and/or mathematics education with content and process of technology and/or engineering education. Integrative STEM education may be enhanced through further integration with other school subjects, such as language arts, social studies, art, etc." (Sanders & Wells, 2010; Sanders, 2013, p. 6).
18. *Interdisciplinary*- intense interaction of multiple disciplines, using knowledge, tools, methods, concepts, and theories of two or more academic disciplines (Sunarti et al., 2020).
19. *Learning taxonomy*- a hierarchal method for defining cognitive and educational goals (Aripin et al., 2020). Bloom's taxonomy (1956) is the first educational taxonomy that is the basis of all other taxonomies used today. Bloom's taxonomy comprises six tiers of cognition; the taxonomy levels were updated in 2001 (Anderson et al., 2001).
20. *Manual Arts*- Manual training and manual arts were created by Calvin Woodward. Manual training would be renamed industrial arts in 1904 (Dugger, 2013).

21. *Multidisciplinary*- integrating multiple disciplines of academic study to solve a problem (Sunarti et al., 2020).
22. *Scientific inquiry*- "Students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others" (NRC, 1996).
23. *Soft Skills*- basic workplace skills employers desire, often called people skills or interpersonal skills (Carnevale et al., 2020).
24. *Socratic Methods of Teaching*- the centuries-old process of asking and answering questions to stimulate critical thinking (Nelson, 1980).
25. *Technology- "*Broadly speaking, technology is how people modify the natural world to suit their purposes. From the Greek word *techne,* meaning art or artifice or craft, technology means the act of making or crafting, but more generally refers to the diverse collection of processes and knowledge that people use to extend human abilities and satisfy human needs and wants" (Duggar, 2000; ITEEA, 2020).
26. *Technical Education*- One of the four ways "technology" can be defined. Refers to the specific training for a trade or industry (Reed, 2018).
27. *Technology Education*- One of the four ways "technology" can be defined refers to the study of the manmade world and adheres to the ITEEA's Standards for Technical Literacy (Dugger, 2000; ITEEA, 2020; Reed, 2018).
28. *Technological Literacy*- "the ability to use, manage, assess, and understand technology. A technologically literate person understands, in increasingly sophisticated ways that evolve, what technology is, how it is created, how it shapes society, and in turn, is shaped by society' (Duggar, 2000; ITEEA, 2020).

29. *Transdisciplinary- integrating* knowledge from multiple academic disciplines and areas of non-academic study (Sunarti et al., 2020).
30. *TSM- is the* acronym for Technology, Science, and Math. The National Science Foundation coordinated the TSM integration project for the middle school curriculum (LaPorte & Sanders, 1993)—a precursor to the STEM acronym.

Summary

The freedom, liberty, and independence of the United States depend on the education of its constituents. The four separate Industrial Revolutions have accelerated change, transforming technology and society. The American educational structure in place today has mostly stayed the same since its inception in 1892 by the NEA. The current curricular frameworks of multiple isolated disciplines provide a literate workforce applicable to employment in manual manufacturing jobs. Employers in the 21st century desire culturally sensitive workers with skills and abilities to create, collaborate, communicate, and be critical thinkers. This study examined how secondary school technology and engineering teachers use the *STEL* practices and frameworks to foster and assess 21st-century learning by integrative STEM methodology, preparing students for prosperous postsecondary endeavors in the 21st century.

CHAPTER TWO: LITERATURE REVIEW

Overview

This chapter provides an overview of the literature and theoretical framework related to the benefits of revising long-established compulsory education in the United States. This overview focuses on the purposeful instruction of 21st -century learning skills taught by technology and engineering teachers that incorporate the *STEL* (ITEEA, 2020) and integrative science, technology, engineering, and mathematics (integrative STEM) methodology in their classrooms. This chapter reviews the literature related to integrative STEM education, current educational frameworks, and 21st-century learning. In the first section, the theories relevant to the STLs, integrative STEM methodology, and experiential learning theory, followed by a synthesis of recent literature regarding the current state of American education and how teaching 21st-century literacy using the *STEL* and integrative STEM methodology are beneficial to all educational stakeholders. Lastly, the literature addresses the challenges of assessing 21st-century literacy and incorporating integrative STEM methodology into mainstream education. In the end, a gap in the literature is identified, presenting a viable need to survey best practices for teaching 21st-century literacy using integrative STEM instruction.

Theoretical Framework

An intelligent person with immense subject matter knowledge only sometimes makes an excellent teacher. To excel as a teacher, one must possess PCK (Shulman, 1986). PCK is the skills and expertise a teacher needs to foster lasting learning. PCK differs with teachers from different disciplines. Integrative STEM methodology is the purposeful instruction of multiple disciplines in design-based learning. This study examines the experiences of teachers who utilize PCK with the expertise of design-based learning.

American Innovation in Public Education

An invention is a product, system, or process that has never existed before, while an innovation is an improvement of an invention (ITEEA, 2020). At this point in history, there are far more innovations than inventions. Americans are adept innovators and have been since the formation of the nation. The United States was established by a group of individuals who recognized the positive and negative aspects of the society and cultures they emigrated from to create the United States of America. The American government is primarily an innovation of ancient Greece's system, not an original invention.

Experiential Learning Theory

Teachers influence their pupils. Quality teachers produce quality students. Thomas Jefferson was influenced by his classical education and studied Socrates, Plato, and Aristotle (Holowchak, 2014). Kolb's experiential learning theory (1978) can interpret this influence. Learning requires interaction with peers and teachers; students learn from experiences and culture (Oleson & Hora, 2014). Jefferson's professors possessed more than pedagogical or content knowledge; they had substantial pedagogical content knowledge (Shulman, 2013). Teachers with pedagogical content knowledge can mesh their understanding of content with a mastery of teaching to foster deeper student learning. Teachers with pedagogical content knowledge produce students who can think critically. Critical thinking, in turn, spurs creativity. While Jefferson noted his dislike for Plato (Holowchak, 2014), he respected many aspects of the Greek government. In The Republic, Plato (1964) stated, "If one is just, one is happy." Jefferson was a natural innovator. Jefferson's ability to think critically allowed him to be happy and a just leader, which helped produce a constitution that was an innovation from Greek culture.

Kolb's experiential learning theory (1984) is like the engineering design process because it is an iterative process that allows the learner to seek improvement constantly. In essence, learners are continually innovating. Jefferson's social interactions led him to become an innovative experiential learner. Jefferson learned about Ancient Greece and then applied his knowledge by helping create our nation's founding documents. Kolb's experiential learning theory is an innovation of nine scholarly theorists, including John Dewey's writings about making and doing (1915; 1916).

Additionally, all engineering design-based curricula, i.e., integrative STEM methodology, is an innovation from Bonser and Mossman's (1923) industrial arts curricular framework. Aristotle (2009) states, "We are what we repeatedly do." History shows that humans are repeatedly innovators and learn best by making and doing. Making and doing allows humans to apply knowledge to solve real-life problems. It is natural to want to innovate and improve the American educational system.

Related Literature

The *STEL* clarify the difference between an invention and an innovation is that an invention is an entirely new technology, and innovation requires a critical analysis of the nature and characteristics of technology to determine a means of improvement (ITEEA, 2020). The American educational system is an innovation of Greek and Prussian educational systems (Lucas, 2016). Innovation is the process of improvement by constantly examining human-made products, systems, and processes to meet a human want or need. This hermeneutic phenomenology critically analyzed the experiences of technology and engineering teachers as the first step in innovating an antiquated educational system.

The Evolution of American Education

Thomas Jefferson and the founding fathers knew the United States would be successful as a nation if its citizens were educated with the skills and abilities to create an independent constituency. The United States lacked the resources to support a disadvantaged population financially. Jefferson wrote the *Bill for Establishing a Public Education* in 1817 (Jefferson & Looney, 2016) to establish a democracy full of educated, independent constituents who would not rely on big government to take care of them.

Today, the goal of public education mirrors the ideals set in place by Jefferson two hundred years ago. The 19th century was partly defined by the Second Industrial Revolution, which established mass manufacturing in the marketplace. Using the same mindset of the 19th century, the U.S. education system has mass-produced workers who possess lower-order thinking skills and very little creativity (Robinson, 2017). The global marketplace is flooded with individuals with essential knowledge and literacy skills, and there is a demand for workers with 21st-century skills.

The mission statement of the United States Department of Education is "to promote student achievement and preparation for global competitiveness by fostering educational excellence and ensuring equal access" (ED, 2010, p. 3; U.S. DOE, 2011). The current education system in the United States produces globally average students, not globally competitive ones. The U.S. governing administration acknowledged the nation’s academic decline early this century and notably implemented the No Child Left Behind legislation of 2001 (NCLB, 2002). U.S. student results on the Programme of International Student Assessment (PISA), which tests 15-year-olds critical and creative thinking ability in mathematics, science, and literacy, produced very average results. In the 2015 study, American 15-year-olds ranked 38th out of 71 countries in mathematics and 24th out of 71 in science and reading (DeSilver, 2020). The ranking of 38th in mathematics was the lowest score the U.S. ever received.

The evolving Industrial Revolutions caused the need for educational reform. Jefferson implemented public education after the first industrial revolution. The Prussian educational system was prevalent in the early 19th century (Lucas, 2016). After the Second Industrial Revolution was well underway, a need for standardization was established, and the NEA's Committee of Ten prioritized mathematics, language arts, social studies, and science, not classical education, as the skills students needed to enter the workforce in 1892 (Mackenzie, 1894). American schools would excel and be the envy of other nations for almost 70 years.

A Nation at Risk report released in 1983 (NCEE, 1983) claimed our education system was eroding and becoming a mediocrity. This was released when the third industrial revolution was underway, and students needed to be trained to enter the workforce with relevant skills at the time. The American educational system produced students with average skills necessary for the third industrial revolution.

Average academic performance is not something educational stakeholders are overlooking. Not just in America but globally, people want public education to improve. The TED Talk with the most views of all time, 22 million and counting (10/2023), is titled *Do Schools Kill Creativity?* by Sir Ken Robinson. Robinson expounds on his famous lecture in his 2017 book with the same title (Robinson, 2017). Educational stakeholders desire improvements to public education. The Standards Movement, No Child Left Behind (NCLB, 2002), and Every Student Succeed Act (ESSA) are focused on appearing to improve by lowering standards and graduating more students.

Globalization, mixed with standardized education, can negatively hurt American students. American workers will lose employment to workers in third-world countries with the same skillset because foreign workers are willing to work for less compensation (Zhao, 2015). Education has now become on-demand. Any student with an internet connection can learn any lower-order skill about any topic. Sal Khan, the creator of the Khan Academy, has noted that education has become a one-world schoolhouse (Khan, 2012). Creativity, innovation, and optimizing student learning are needed for American workers to prosper in the Fourth Industrial Revolution.

For students in the United States to be globally competitive, they need to experience education differently in the 21st century. Students need to learn creativity and innovation while collaborating and learning to communicate more effectively. The education system is not broken but outdated (White, 2011). Education needs to become more efficient and share a unified mission and vision. Integrative STEM education offers educational stakeholders a new experience and a way for educators to become more efficient. Integrative STEM provides a methodology to enhance the current education setup of isolated disciplines, not displace them (Sanders, 2015).

Goals of Compulsory Education

Snow (1959) described a world split into two groups: the arts and the humanities. The educational landscape in the 21st century is more of an archipelago consisting of numerous independent islands. In a world that has become constantly connected via the internet, education in American public schools is very disconnected. The American educational landscape consists primarily of numerous monodisciplinary groups. Each discipline has established its governing body and created unique mission and vision statements.

Compulsory education is required by all graduates and is imposed by the government. The state of Virginia has two primary diplomas, standard and advanced studies. For both Virginia diplomas, there is a minimum requirement of thirteen courses in four disciplines: four courses of English, three courses of mathematics, three courses of social studies, and three courses of science. Virginia compulsory education also requires a minimum of five verified credits. The course is supplemented by passing a standardized exit exam in reading comprehension, writing, math, science, and social studies (VDOE, 2022).

The vision statement for the VDOE is that Virginia schools will "maximize the potential of all learners" (VDOE, 2022, n.p.). The VDOE mission statement aims to "advance equitable and innovative learning" (VDOE, 2022, n.p.). The mission and vision for the state of Virginia have clear goals to establish 21st -century learning. The conglomerate of isolated disciplines relied on to meet Virginia's mission and vision still has antiquated 19th-century goals. If each discipline would collaborate multi-disciplinarily with integrative STEM teachers or be trained to teach using integrative STEM methods, their mission and vision would produce better-prepared 21st-century learners.

Goals of the Core Disciplines

Every Virginia discipline has a state chapter of a national education association and adheres to each national mission and vision. The following sections detail the overarching goal(s) and purposes of each discipline and its professional organization. The core subjects of mathematics, English, science, and social studies, with their corresponding professional organizations, are listed first, followed by all other disciplines and affiliated organizations.

Mathematics. The Virginia Council for Teachers of Mathematics has a monodisciplinary approach, focusing solely on the improvement of mathematics at the local, state, and national levels. (VCTM, 2023). The mission statement for the National Council of Teachers of Mathematics (NCTM) advocates for high-quality mathematics teaching and learning (NCTM, 2022). The phrase "high-quality mathematics" is an ambiguous term. The VCTM and the NCTM both desire 21st-century math skills to be taught; however, they still utilize 19th-century monodisciplinary methods. The NCTM released a position statement regarding STEM education explaining that STEM activities were merely enrichment activities to be done after mathematics instruction was prioritized (NCTM, 2018). The NCTM must acknowledge that 21st-century mathematics is necessary for all disciplines. While 19th-century mathematics was taught as an isolated, stand-alone discipline, 21st-century mathematics education utilizes interdisciplinary instruction and revised pedagogical content knowledge. Pedagogical content knowledge is how teachers introduce content that connects mathematics to real-world problems (Paolucci & Stepp, 2021; Shulman, 2013). High-quality mathematics in the 21st century is only possible if the knowledge gained is applied to solve real-world problems.

English. The Virginia Association of Teachers of English (VATE) has a monodisciplinary approach to meet the needs of all levels of English Language Arts instruction (VATE, 2023). The mission statement for the National Council of Teachers of English strives to produce a literate society (NCTE, 2022). The ability to articulate ideas properly and communicate effectively has been a priority for public education for centuries. Sir William Curtis, an illiterate English politician, coined the saying "reading, 'riting, and 'rithmatic" in 1795 to the English Board of Education, stating the importance of the three "R's" in public education (Curtis Dolby & Brazil, 2010). Reading comprehension and writing have been the primary focus of public education for over two centuries. The only two subjects mentioned in the entirety of the NCLB legislation (2002) were mathematics and the English language.

The expectations of English language teachers in the Commonwealth of Virginia and throughout the United States continue to expand. Reading comprehension is a foundational piece to learning any other discipline. More importantly, language learning is the backbone of communication. English language learning is much more than reading and writing. 21st-century learning encompasses various types of communication, including digital communication and digital literacy, soft skills and being able to use the English language in the workforce, and technical and engineering literacy to articulate designs and collaborate with team members.

Science. The Virginia Association of Science Teachers (VAST) incorporates a multidisciplinary approach by noting the importance of partnerships in the mission statement (VAST, 2023). VAST is an affiliate of the National Science Teacher Association (NSTA). The mission statement of the NSTA also notes the importance of partnerships (NSTA, 2022). Virginia science educators are cognizant of the importance of partnering with other disciplines. In 2014, the Virginia Department of Education reduced the number of end-of-course standardized SOL tests. No mathematics SOLs were eliminated; however, 80% of the tests eliminated were science and social studies SOLs (VDOE, 2015). This is a clear indication that science education is not valued as highly as the mathematics and English language disciplines.

Science education is trying to better train pre-service teachers in PCK. The refined consensus model (RCM) is being researched worldwide to better explain the three realms, collective, personal, and enacted, of PCK (Behling et al., 2022). Science educators are firmly rooted in the educational caste system, accepting their position as less important than mathematics and English but more important than other disciplines. For example, the NSTA standards address engineering design via scientific inquiry (NSTA, 2022), a completely different process than engineering design taught by technology and engineering teachers.

Science education could benefit from referring to its national mission statement and partnering with T&E teachers to solve some of the world's unsolvable problems. The 14 Grand Challenges of Engineering (NSF, 2022) possibly remain unsolved because leaders of science did not adequately partner with leaders of other disciplines. Integrative STEM PCK would allow teachers to search for the best possible solution anywhere, not just in science.

Social Studies. The Virginia Council for the Social Studies (VCSS) has a monodisciplinary approach focusing only on those in the social studies community (VCSS, 2023). The VCSS is an affiliate of National Council for the Social Studies (NCSS). The mission statement of the NCSS focuses mainly on establishing high-quality social studies (NCSS, 2022). However, The NCSS vision statement focuses on creating lifelong learners capable of fulfilling their civic duty (NCSS, 2022).

Social studies educators have the most progressive vision statement of the core subjects, noting the skills needed to interact in society. This may be because legislation deemed social studies teachers the least important of the required disciplines. In 2014, Virginia reduced the number of SOL tests from Grades 3-12. More social studies tests were eliminated than any other SOL-tested discipline (VDOE, 2022). The NCSS vision statement aligns well with the STEL (ITEEA, 2020) because the vision statement acknowledges that lifelong learning is a process, not a product, and touches on the optimism piece of the STEL, which prioritizes the inclusion of all learners. Social studies are one of the few areas of Virginia public education that does not have a critical shortage of teachers (VDOE, 2022). This may be a great starting point for teacher collaboration and integrative STEM methodology to relate social studies content to real-world design problems.

Goals of Non-Core Disciplines

Both core classes and non-core classes have widely different mission and vision statements. Table 1 (Appendix C) contains the mission and vision statements for seventeen other professional education associations. All Commonwealth of Virginia chapters of professional associations abide by their parent chapter's mission and vision statements. The only consensus in all professional teaching associations is that education should be equitable and available to all children. Fifteen of the seventeen organizations listed are focused on monodisciplinary instruction. Only two professional organizations actively call for accelerated innovation and integrative STEM education. The two organizations are the only organizations that have published standards for 21st-century learning, the *Standards for Digital Literacy* and the *Standards for Technological Literacy* (ISTE, 2022; ITEEA, 2022).

American education believes in “do as I say, not as I do.” Educators worldwide proclaim the need for 21st-century learning. Students need to learn communication, critical thinking, collaboration, and creativity. Educators encourage students to communicate and collaborate, yet as professionals, educators rarely share and collaborate with teachers of other disciplines to creatively teach students multidisciplinary projects. Educators default to how they were trained primarily by 19th-century methods. Teachers teach how they feel best taught (Oleson & Hora, 2014). Teachers define creativity and critical thinking by the experiences of their educational journeys. Teachers will not change their teaching style until they experience learning in a classroom where the educator has exceptional 21st-century pedagogical content knowledge (Shulman, 2013).

Technology and engineering teachers have always been forward-thinking. Calvin Woodward adapted his manual arts instruction to meet the needs of a society transitioning from the first to second industrial revolutions (Dye, 1974). The ITEEA was founded in 1939 and was first titled the American Industrial Arts Association (AIAA). The AIAA had its first national conference in 1947 with the theme “A Curriculum to Reflect Technology” (Dugger, 2013). The AIAA correctly used the term “technology,” meaning the study of the man-made world, and recognized a society transitioning from the second industrial revolution to the third. Technology and educators would continue to monitor the needs of a changing world and provide professional name changes to technology education in 1985 and integrative STEM education in 2009 (Dugger, 2013; Sanders, 2009). While industrial arts, technology education, and integrative STEM education have primarily been taught on the secondary level, educators in Virginia have established the Virginia Children’s Engineering Council to teach 21st-century skills to PK-5th-grade students (VCEC, 2022).

The National Assessment of Educational Progress (NAEP) has coined itself the nation’s report card and uses the standardized test to measure the progress of American education (NAEP, 2022). The good news is that NAEP tests technology and engineering, and the second edition of the STEL is referenced in the NAEP framework of assessment. In the standardized test summative exam, 8th graders were only correct on 50% of the questions in 2014 and 2018 (15,400 students) compared to 147,400 students tested in math (NAEP, 2022). The 50% correct data is a “glass half-full” scenario, testing higher-order thinking with a lower-order assessment. The NAEP has not retested technology and engineering since the STEL was revised for the third edition in 2020.

The mission statement for the Virginia Board of Education is “to develop policies and provide leadership that improves student achievement and prepares students to succeed in postsecondary education and the workplace, and to become engaged and enlightened citizens.”

(VDOE, 2017, p. 5). Improving student achievement requires innovation. Technology education teachers define innovation as the improvement of an invention. History shows educators have sought to evolve but resorted to 19th-century methods. There is very little social learning in the disciplines and very little collaboration between teachers of different disciplines. For 21st-century learning to occur, there needs to be an innovation of established 19th-century methods.

The Evolution of Integrative STEM Education

Before the NEA's Committee of Ten frameworks, a forward-thinking educator realized that students need the opportunity to apply knowledge to a real-world task. Calvin M. Woodward, a Harvard-educated math professor, realized his students needed a way to apply the math concepts he was teaching. Woodward took his students to the woodworking shop to create projects using the knowledge they learned in his class. Woodward's actions spurred the manual school movement, the precursor to vocational and technical education (Dye, 1974). The field of manual training would incur a name change by Charles Richards in 1904 and be subsequently referred to as industrial arts. The field of industrial arts officially changed its professional title to technology education in 1985 (Dugger, 2013). Technology education would be rechristened to integrative STEM education in 2009 (Sanders, 2009).

As of 2023, the American K-12 education system primarily uses direct instruction in isolated disciplines. Direct instruction in isolated disciplines fostered skills once needed for the Second Industrial Revolution when lower-order thinking skills and manual labor were required for numerous analog manufacturing jobs. As of 2016, college enrollment and literacy rates were higher than ever in history (Lucas, 2016). While being literate in the Second Industrial Revolution workforce was desirable, merely being literate allowed applicants to attain entry-level jobs in the 21st century.

A century ago, a high school diploma was beneficial in the job market, and a college degree was a rarity. Only 2% of those qualifying to attend college enrolled (Robinson, 2017). The GI Bill aimed to increase college enrollment and paid tuition for members and veterans of the U.S. armed forces and was awarded to soldiers returning from World War II and the Korean War. The GI Bill catalyzed the third industrial revolution, the start of the digital age. More educated people created more innovation, propelling the global economy to heights. As the world shifted to the digital age, a college degree was necessary for many well-paying jobs. The world economy has continued to evolve into the fourth industrial revolution, a globalized, automated, and constantly connected world. A college degree does not guarantee a promising career or decent job in the globalized economy. The job market is saturated with college graduates; however, workers who are innovative problem-solvers are likelier to earn higher compensation. An integrative STEM methodology, an interdisciplinary/multidisciplinary way to teach problem-solving using engineering design projects, can foster higher-order thinking needed to create and innovate.

Evolution of Acronyms

Snow (1959) greatly influenced the National Science Foundation (NSF). The NSF was created at the beginning of the third industrial revolution to meet the needs of globalization. As the world quickly entered the fourth industrial revolution, the NSF would try to address Snow's theory using interdisciplinary approaches to solve real-world problems. The NSF established the Technology, Science, and Mathematics (TSM) project, which developed twenty hands-on projects for middle school technology education programs to teach abstract math and science using purposeful hands-on projects. The success of the TSM project let the NSA add engineering design and the E to the methodology. The new methodology was known as SMET education, later called STEM education (Laporte & Sanders, 1993; Stevens, 1993). In 2009, Sanders and Wells finalized their definition of integrative STEM, which called for the purposeful instruction of multiple content areas using design-based learning. This definition stressed the importance of learning multiple content areas, even if the content area was not listed in the acronym STEM. With the disparity and confusion around STEM vs. integrative STEM, the Rhode Island School of Design was the first to officially add the "A" to STEM, creating the STEAM acronym. Sanders and Wells (2009) and the Rhode Island School of Design acknowledged that the sciences and the humanities needed to start working together, effectively stating that the purposeful inclusion of the arts and creativity in STEM disciplines would foster more globally competitive students (Allina, 2018).

Clarifying the STEM Acronym

The definitions of the STEM acronym's S, T, E, and M are ambiguous to various content area teachers. The S and M appear to be the least ambiguous because science and mathematics are core area classes in most K-12 schools. The M is the easiest to define because it is the most isolated. M stands for mathematics, the language of numbers. Mathematics overlaps almost every content area of education. However, educators agree that students must be enrolled in math classes to learn mathematics truly. For the better part of the 20th century, the S, or science, was easily defined as “the study of the natural world.” At the beginning of the 21st century, educational budget cuts forced science to be an elective subject. Leaders in science education wisely revised K-12 science standards (NRC, 2012). Current K-12 science standards contain the wording “scientific inquiry” and “engineering design.” Science educators argue that science classes continue to be a core subject because they teach the S and E, half of STEM education. Today, “technology” is defined in four ways (Reed, 2018).

The “T” in STEM represents different things to different groups. The “T” can represent instructional or educational technology, which enhances the teaching and learning process. Education technology teachers are governed by the International Society for Technology in Education (ISTE) and adhere to universal standards to safely and properly use technology in education. The “T” can represent technology education, which studies the manmade world and adheres to teaching the ITEEA’s Standards for Technical Literacy (Dugger, 2000; ITEEA, 2020). Technology Education is governed by the International Technology and Engineering Educators Association (ITEEA), which claims that the “T” and the “E” are dependent upon one another, stating that all technology education classes use engineering design to learn about the man-made world. The “T” can also mean technical education or specific training for a trade or industry. Confusion arises because technology education classes and technical education classes are both offered under the CTE umbrella in secondary education. The “T” also stands for information technology, synonymous with computer programming, communication, and networking. Engineering educators agree that the “E” in STEM stands for engineering design but argue that engineering educators must primarily teach engineering education. The “T” stands for educational technology or instructional technology. The National Research Council (NRC) established K-12 engineering education standards in 2009 (NRC, 2009).

STEM needs to be clarified because there are four definitions for technology and three governing bodies establishing standards for engineering. For this study, the definition of STEM will align with the definition of integrative STEM education (Sanders & Wells, 2010). To clarify Sanders and Wells's (2010) definition, “technology” can be simplified to mean studying the man-made world. The definition of “science” would be the opposite. Integrative STEM is learning about everything on the planet, using every available resource. It is an open-note, open-book collaboration to make the world a better place to live. Educators are encouraged to work together, not claim territory in the educational landscape. Integrative STEM methodology is a student-centered, not teacher-centered, way of teaching and learning.

21st-Century Learning

21st-century learning needs a universal definition. Educational reform has created a plethora of ambiguous buzzwords (Dede, 2010). One confusing term is the STEM acronym. Parts and the whole meaning of the STEM acronym mean different things to different groups (Reed, 2018). In today's culture, if a person does not know an answer to a query, they most likely use the internet and a search engine to find a list of possible solutions. Possible answers, just like technology, are growing exponentially. If one searched "21st-century learning" or "21st-century skills" in 2018, there were over 600,000 results to the query (Kelley et al., 2019). Today (October 2023), if the same query is searched on Google Scholar, over 3.4 million results are generated.

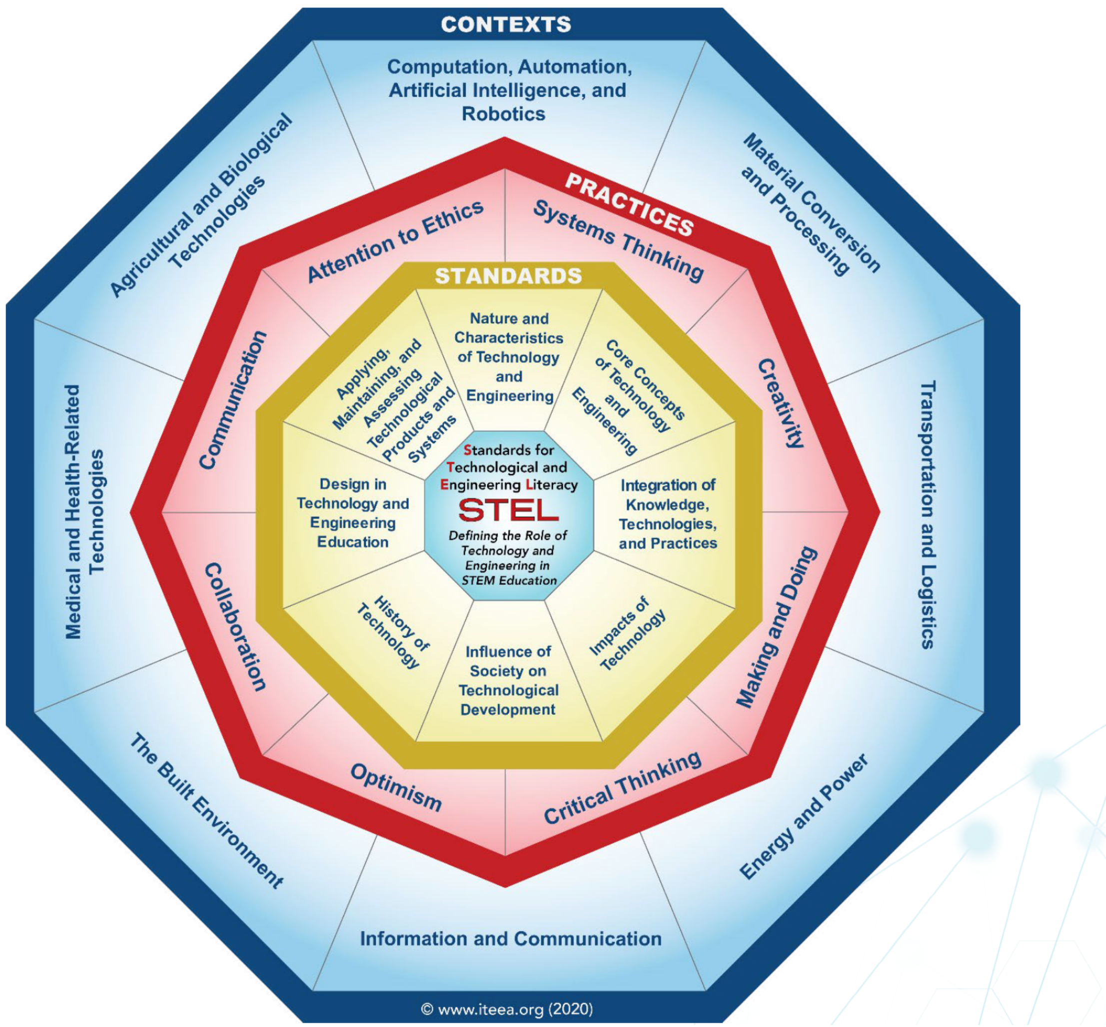
In broad terms, 21st-century skills are needed to succeed in the 21st-century marketplace. A person's cognitive abilities are more valuable in today's economy than their brawn. 21st-century skills can be defined as learning skills, literacy skills, and life skills needed to adapt to a workforce that has shifted from focusing on manual labor to human capital (van Laar et al., 2020). The definition can be simplified by remembering the four Cs: communication, collaboration, critical thinking, and creativity (Colton et al., 2020; Nadiroh et al., 2021).

Numerous organizations have developed frameworks to define and implement 21st-century curricula in the past twenty years. The list includes the P21 Partnership for 21st Century Learning (P21, 2022), The North Central Regional Educational Laboratory (NCREL) enGauge 21st Century Skills (NCREL, 2003), the Organization for Economic Co-operation and

Development (OECD, 2005), the American Association of School Librarians (AASL, 2009), the Common Core State Standards (CCSS, 2022), the *STEL* (ITEEA, 2020), the International Society for Technology in Education *Standards for Digital Literacy* (ISTE, 2022), and Georgetown University's Center on Education in the Workforce's *Workplace Basics* (Carnevale et al., 2020). All entities have valid and varying definitions of 21st-century learning. All frameworks contain the 4 Cs of 21st-century learning: creativity, critical thinking, collaboration, and communication. The STEL and the ISTE standards both stress 21st-century literacy, technological literacy, and digital literacy, respectively. In essence, 21st-century learning is developing skills that develop workers who use their mental facilities to the utmost. Figure 1 below shows a graphic representation of a 21st-century learning model created by the ITEEA (2020).

Figure 1

21st-Century Learning Model



International Technology and Engineering Educators Association (ITEEA). (2020). *Figure 2.1 Three technological and engineering organizers for teaching* [Image]. *In Standards for technological and engineering literacy: the role of technology and engineering in STEM education* (p.11). www.iteea.org/STEL.aspx

Differences Between Technological and Digital Literacy

Technological literacy is one's ability to use, manage, evaluate, and understand technology (ITEA, 2000; ITEEA, 2020). Digital literacy is the knowledge and ability to use digital technology (ISTE, 2022). A broad definition of "technology" is the study of man-made items. Therefore, technological literacy encompasses digital literacy and means a learner understands how to use man-made tools and systems that are both digital and analog.

Updating Compulsory Education

American educational stakeholders have desired revision of compulsory education since the release of the "America at Risk" report in 1983 (NCEE, 1983). The report noted the need for updating compulsory education to match the needs of the workforce that merged into the third industrial revolution. As globalization occurred and the world shifted from the third industrial revolution to Industrial Revolution 4.0, more and more demands for change have been made. The most noted educational legislation in history, No Child Left Behind (NCLB, 2002), aimed to improve all education while only addressing two isolated disciplines. All other academic disciplines have followed suit, devising revisions that primarily address monodisciplinary issues of updating compulsory education.

P21 claims to be a pioneer in 21st-century learning. The P21 organization was started in 2002 by a group of individuals, businessmen, educators, and the U.S. Department of Education. The P21 21st-century frameworks were first released in 2007 (P21, 2022). Kelley et al. (2019) noted the 2009 P21 framework definitions as inspiration for their study. The 2009 P21 definitions focus only on the skills of creativity, critical thinking, communication, and collaboration (P21, 2009. By noting the four C's, the P21 group acknowledges that numerous things need to change to revise compulsory education.

The P21 partnership for 21st-century learning lists sixteen essential disciplines to teach the 21st-century curriculum. P21 makes a glaring omission. Technology nor engineering education are listed in the 16 essential disciplines. While there is a clear intention and desire to improve educational practices, the P21 framework attempts to teach 21st-century skills with 19th-century methods. As shown in Figure 1 above, the P21 standards are still focusing on the 3 R's, monodisciplinary instruction, and only addressing digital technology.

The P21 framework divides all learning into the 3 Ls: life, literacy, and learning skills (P21, 2022). Several other frameworks focus on improving 21st-century learning but only focus on one L. Georgetown's Center for Education in the Workforce's *Workplace Basics* (Carnevale et al., 2020) focuses primarily on life skills or the soft skills one needs to succeed in the workforce. The ISTE standards for digital literacy (2022) provide an excellent guide for literacy but are entirely in the digital realm. The Common Core State Standards (CCSS, 2022) focus on literacy and learning skills, but only for the four disciplines of English language, mathematics, social studies, and science. *The STEL* (ITEEA, 2020) addresses the 3 Ls through eight practices of making and doing, systems thinking, attention to ethics, optimism, collaboration, communication, creativity, and critical thinking. The following pages will address 21st-century learning through the eight *STEL* practices.

Making and Doing

Learning without the application of knowledge is like cooking without tasting. Making and doing is the cornerstone of integrative STEM education. From the foundational roots in manual arts training, industrial arts education, and technology education, making and doing have been essential pedagogy. Making and doing in integrative STEM is far more than making crafts. Making and doing is a design-based iterative process (ITEEA, 2020), meaning students are doing hands-on and mind-on projects that require planning, defining, creating, testing, reflection, and revision.

Integrative STEM methodology requires a paradigm shift from having the teacher be the worker and the student be the product to having the teacher be the facilitator, the student be the worker, and their skills be the product. Design thinking is a flexible tool that bridges the gap from standardization to engagement and requires whole-brain thinking (Lord, 2019). The pedagogical design of transdisciplinary learning enables the creation of new categories of education where multiple disciplines excel (Sengupta et al., 2019). Education does not have to be boring. Learning should be fun and captivating, so teachers should teach content and engage students through an exciting medium. For students to succeed in the 21st century, they must learn to apply knowledge by making and doing. Integrative STEM methodology can engage all students in all disciplines with hands-on, minds-on design projects.

Classroom Safety. Industrial arts and technology education classes are grouped under the career and technical education (CTE) umbrella and were once associated as educational "dumping grounds" for students cast off from other disciplines. The systematic funneling resulted from race, gender, income, achievement, and disciplinary issues (Giani, 2019). As a result of being stigmatized as a dumping ground, classrooms with equipment became safety concerns. Learning areas in industrial arts classrooms, laboratories, shops, maker spaces, etc., continue to be branded as unsafe.

For almost a century, shop and lab safety has been a priority and continual research topic for career and technical educators (ICODSH & Krise, 1966; Love et al., 2023; Stone, 1953; Vizzi & Cardoso, 1951)—safety issues and stereotyping plagued traditional industrial arts classrooms. Clark (1989) explored the notion that the traditional woodworking shop was on the verge of extinction. Technology and engineering teachers and CTE teachers did something their peers in many other disciplines did not; they updated their curriculum and evolved with the

Industrial Revolutions. Research shows that students in CTE classes are more likely to go to college than those not enrolled in CTE classes (Giani, 2019). The Virginia Department of Education implemented legislation limiting the number of students in an area with equipment to be capped at 20 students. It implemented a Virginia *CTE Safety Guide* for all educators (VDOE, 2022). Tool manufacturers designed and produced life and limb-saving innovations to woodworking saws; Saw Stop brand table saws, which feature an emergency braking system when moisture or skin is detected, are now a fixture in almost every school in Virginia (Sawstop, 2022).

Most importantly, non-technology and engineering teachers are being trained in laboratory safety (Love, 2022). Teachers are given a safety framework (Love et al., 2020) and instructed on implementing integrative STEM projects that had prior reservations about teaching with tools and machinery. This professional development has changed the perception and promoted the self-efficacy of teachers desiring to teach 21st-century curricula. More professional development opportunities are needed to eliminate concerns regarding classroom safety and empower teachers and students with 21st-century skills.

Etymology of Technology. The modern definition of technology is the “human-designed products, systems, and processes that satisfy wants and needs” (ITEEA, 2020, p. 21). Technology is derived from the Greek word *tekhne,* meaning “art, craft, skill, or to fabricate” (American Heritage Dictionary, 2022). English translations of *The Holy Bible* have recorded the occupation of Jesus Christ of Nazareth as a carpenter (*New International Version*, 1984/2011, Matthew 13:55); however, the official name of Jesus’s occupation was a *tekton,* meaning artisan/craftsman*.* Jesus was an apprentice of his earthly father, Joseph, and he learned how to fabricate numerous types of materials because wood was scarce in areas Jesus lived in as a young man (Renner, 2022). Jesus Christ learned how to become a master craftsman by making and doing. By designing and creating products, systems, and processes to satisfy wants and needs, humans are Christlike (*New International Version*, 1984/2011, 1 John 2:6; 1 Peter 2:21). Creating technology by making and doing is defined as a 21st-century skill; however, it is more of a timeless skill. The application of knowledge to meet a want or need is the cornerstone of all higher-order learning.

Systems Thinking

Including systems thinking in education reform is ironic. There has been a disconnect between disciplines for decades, first acknowledged by Snow (1959). Systems thinking is the understanding that all technologies have interconnected components that interact in their social and natural environments (ITEEA, 2020). Systems thinking acknowledges that disciplines are interconnected. System thinking requires “big picture” cognition. Systems thinking is needed for design thinking (Buchanan, 2019). Design thinking is necessary for integrative STEM methodology and relating content knowledge to real-world problems, but it can also be introduced to students in fun and motivating ways. Systems thinking can be taught by introducing students to designing their own Rube Goldberg machines to show how every event causes a reaction (Kim & Park, 2012). Once educators realize integrative STEM methodology is a system, valid and lasting improvements can occur.

The internet defines the fourth industrial revolution and how it creates a constant connection (Pouspourika, 2020). For students to become 21st-century learners, they must become system thinkers and understand the complexity of relationships the world offers. More importantly, students must learn that the eight *STEL* practices affect one another.

Creativity

Creativity is the most researched skill desired in the 21st-century workplace (van Laar et al., 2017). Creativity has a distinct, mysterious quality (Kim, 2019) and has numerous definitions. In 1961, Rhodes examined 40 definitions and simplified them into the 4 Ps of creativity. Rhodes (1961) explained that creativity occurs in four natural states. The 4 Ps are person, process, product, and press (environment). A person can be creative, a process can be creative, a product can be creative, and an environment can be creative.

Sawyer (2011) explains that creativity has individualist and sociocultural definitions. The individualist definition of creativity is the process of inventing (making completely new products/processes) and/or innovating (improving existing products/processes) (ITEEA, 2020). The socio-cultural definition of creativity is that it is established and judged by a peer group (Sawyer, 2011). Creativity is the highest form of learning (Anderson et al., 2001; Bloom, 1956), and it promotes and sustains deep learning (Ostroff, 2016). Integrative STEM methodology offers educators a way to introduce and cultivate the multiple forms and definitions of creativity to produce 21st-century learners.

Critical Thinking

Almost every American student over 30 learned their multiplication tables from sheer repetition. Excessive repetition is also called “memorization for regurgitation.” A state of remembering facts without understanding why. Critical thinking, however, is the process of reflective thinking, an analysis of facts (Hullfish & Smith, 1961). Furthermore, conceptual understanding is the foundation of critical thinking and spurs creativity (Ozkan & Umdu Topaskal, 2021). The *STEL* (ITEEA, 2020) simplifies critical thinking to be decision-making.

Decision-making can be as simple as soft skills or interacting with others in a work environment, as complex as solving one of the fourteen unsolved engineering grand challenges (NAE, 2022). Self-reflection is the most important piece of critical thinking, as it affects 21st-century learning. Assessment of 21st-century learning will require more than multiple-choice tests and students to be self-aware of what they have and have not learned (Kelley et al., 2019; Roman & Aurel Vlaicu, 2022). 21st-century learners strive to understand "why," and if "why" cannot be determined, they take the following steps to reflect on who, what, where, and how the problem can be solved.

Collaboration

Learning is a social process (Vygotsky, 1978), and behavior is a function of each learner (Lewin, 1936). While learning is naturally collaborative, the assessment of learning is currently individualized. Virginia public school students are given 29 SOL tests between third grade and graduation. Students are required to pass six end-of-course SOL tests for graduation (VDOE, 2022). All 29 SOL tests and every grade in every discipline are individual. Isolation, not collaboration, is the current state of education in Virginia.

Collaboration between learners and educators is paramount in developing 21st -century learners (De la Garza & Travis, 2019; Stewart et al., 2020; Trott et al., 2020). The following gives examples of recent research that shows collaboration in various classroom environments.

Classroom Orientation and Active/Atypical Classrooms. Student collaboration can start as early as kindergarten (Eckhoff, 2020), and integrative STEM transdisciplinary learning can occur in many non-traditional environments. All CTE classes are a natural fit for collaboration in integrative STEM instruction. One study of collaboration happened in a home economics class (Haapaniemi et al., 2019). Collaboration can be active and occur outside of a desk in STEAM-based physical education (Lee, 2021). Differentiated learning and collaboration can occur in special education classrooms (Park, 2021). Students can work in groups to design and create in maker spaces (Koul et al., 2021). Future classroom laboratories will be designed and look far different than traditional learning environments (Colton et al., 2020). 21st-century learning is intended to be possible anywhere and continues throughout the learner's lifetime.

Workplace Readiness Skills. Collaboration is vital, not only in the classroom but in the workforce as well. Being able to collaborate and work effectively with coworkers is a skill that future employers demand (Carnevale et al., 2020). Technology and engineering, and Integrative STEM educators fall under the CTE umbrella and are required to teach workplace readiness skills (VERSO, 2022). Students learn 22 competencies that include soft skills, teamwork, collaboration, communication, problem-solving, and critical thinking as part of every CTE class in Virginia. Workplace readiness skills are recognized at the higher education level as well. Georgetown University has produced a list of workplace basics and qualities employers desire. The two most desired skills for future employees are communication and teamwork skills (collaboration), and the two least desired skills to make the list are humanities skills (ancient languages, philosophy, performing arts) and strength and coordination skills (Carnevale et al., 2020). This list shows an abundance of workers available with skills valued in the 19th century, both classically educated and with skills intended for mass manufacturing and physical labor. Twenty-first-century learning and 21st-century life require soft skills to succeed.

Communication

Positive digital and in-person communication are foundational requirements for the global workplace. The *STEL* (ITEEA, 2020) defines communication as how one articulates one's ideas. Communication goes far beyond just words spoken or written. Communication encompasses non-verbal communication as well. Negative communication occurs when someone fails to show interest or respect to someone attempting to communicate and wears inappropriate attire (Hastings et al., 2020). To become literate in 21st-century skills, students must learn to communicate positively with others. Communication is the foundation of soft skills taught in all Virginia CTE courses as workplace readiness skills.

Optimism

Technology and engineering education classrooms are optimistic because they motivate students to succeed (ITEEA, 2020). The *STEL* (ITEEA, 2020) simplifies optimism to mean the persistence to improve continually. Engineers, designers, and innovators always try to improve the current system or product. Students are required to analyze trade-offs and strive for optimal results. Integrative STEM classrooms are optimal because they welcome all genders, races, and academic abilities to collaborate and innovate a better world.

Promoting Gender and Racial Diversity with Integrative STEM. Societal norms in America have completely changed in the last 160 years. American schools were segregated for nine decades after the American Civil War. Industrial training in colored schools was focused more on the body than the mind (Washington, 1903). Segregation of schools caused adverse effects by displacing quality teachers of color (Hall, 1973). Additionally, even after segregation, females were prohibited from enrolling in industrial arts classes (Dye, 1974). Over time, technology and engineering teachers have been persistent in their work to improve their field and the world itself.

Integrative STEM classrooms motivate students by being all-inclusive environments with a student-centered culture (Conradty & Bogner, 2020; Eckhoff, 2020; Geesa et al., 2021). Integrative STEM classrooms welcome both genders and all cultures and races to learn collaboratively (Chu et al., 2019; Walan, 2021). Education inequality can be eliminated by using integrative STEM education and the STEL to teach 21st-century skills (Zhao, 2016). A place where all can learn is the true definition of optimism.

Attention to Ethics

Culture establishes societal values, and values develop ethics. The *STEL* (ITEEA, 2020) states that ethics is the cornerstone of a stable society. There are numerous cultures and a wide range of values in the United States (Sneider & Zhu, 2020; Stephens, 2019). One could argue that there has been far more ethical change than educational change, and the ethical change affects teacher satisfaction and performance (Limna et al., 2022). Academic dishonesty has become widespread in online learning in the post-pandemic era (Harton et al., 2019; Shalevska, 2021). Learning respect for others, respect for the environment, and ethical consideration for emerging technologies (Lajoie et al., 2020) are critical lessons each learner needs to become a 21st-century learner.

Integrative STEM, not STEAM for 21st-Century Learning

Both STEAM and Integrative STEM are in their infancy and have ambiguous meanings. There is a debate about what precisely the "A" in STEAM also stands for. The STEAM methodology offers educational stakeholders the multidisciplinary opportunity to apply content knowledge to solve real-world problems (Khine & Areepattamannil, 2019). STEAM methodology fosters collaboration, creativity, and entrepreneurship and develops 21st-century skills to be globally competitive. The STEAM methodology also educates students in an all-inclusive setting. The main difference between STEAM and Integrative STEM is explicitly using a design-based pedagogy to transfer knowledge gained into solving problems. The ITEEA also governs integrative STEM and has established standards, the STEL (ITEEA, 2020); STEAM does not have a governing body, a curricular framework, or a set of standards. STEAM instruction could mean students make arts and crafts in math class, not necessarily solving a problem. While both methodologies enhance and foster high-order thinking, integrative STEM methodology is more viable in the global economy. If students are trained to view every problem as a design-based issue they must solve, they enter the workforce as natural problem solvers.

Education in the United States is slowly transitioning away from a monodisciplinary approach. More and more educators are collaborating to create interdisciplinary curricula (Henseler, 2020). Integrative STEM and STEAM both have similar end goals. Both methodologies want to include multiple disciplines in learning, leaving no discipline out of the equation or creating a hierarchy of disciplines (Stewart et al., 2020). Integrative STEM is "...technological/engineering design-based learning approaches that intentionally integrate science and process of science and/or mathematics education with content and process of technology and/or engineering education. Integrative STEM education may be enhanced through further integration with other school subjects, such as language arts, social studies, art, etc." (Sanders & Wells, 2010). Integrative STEM instruction is much more than STEM or STEAM (STEM with the addition of “arts”). Integrative STEM methodology can be multidisciplinary, interdisciplinary, or transdisciplinary and can be taught by one or many instructors. Integrative STEM education aims not to reconfigure the educational landscape but to enhance the foundation established over the past 130 years.

Integrative STEM education utilizes experiential learning theory, a synthesis of prior frameworks Dewey’s learning-by-doing theory (1915; 1916), Follet’s management theory (1918), James’ James-Lange Theory of Emotion (1890), Freire’s critical consciousness and critical pedagogy (1970; 1973), Vygotsky’s social constructivist theory (1978), Jung’s collective unconscious (1969), Piaget's cognitive development and children's adaptation to environment theories (1929; 1953), Lewin's change theory (1939), and Rogers' humanistic approach (1959). Integrative STEM education is based heavily on Dewey's (1915; 1916) learning-by-doing theory and Vygotsky's (1978) social constructivist theory (Kolb, 1984; 2014). Experiential learning theory is a learning theory that explains that people learn through direct experiences or learning by doing. Social constructivists use tactile objects and tools to complete hands-on projects, address learning of specific physical skills, and prioritize learning socially with others (Dewey, 1915; 1916; Vygotskӱ, 1978). Hands-on, minds-on curricula are often the exact opposite of what is currently being taught in American secondary schools, where instruction primarily presents conceptual and abstract ideas. Experiential learning theory is the process of using knowledge gained for direct use in education or the workforce. A perfect example of experiential learning theory meshing with social constructivism is when students work in groups to complete integrative STEM projects and use the knowledge and experience gained to be globally competitive in the marketplace.

Benefits of Teaching 21st-Century Skills with Integrative STEM Methodology

21st-century skills are embedded into every job in the globalized marketplace. 21st-century skills are compensated greater than 19th and 20th century skills. Interdisciplinary instruction provides educators with the perfect medium to teach 21st-century skills. In a 2019 study, 50 of 67 lesson plans at inclusive STEM high schools purposefully teach 21st-century skills (Stehle & Peters-Burton, 2019). The global business landscape continually changes, and students must learn to be forward-thinking. 21st-century classrooms must produce human capital (Sima et al., 2020) and instruct students in entrepreneurship education (Stenard, 2021).

Challenges of Implementing 21st-Century Learning

There are numerous hurdles to implementing 21st-century learning, such as assessment, funding, legislation, teacher training, career counseling, teacher shortages, and evolving methods of instruction. A primary challenge of implementing 21st-century learning is providing adequate assessment data so that revised teaching methods are working. No uniform streamlined process of assessment provides clear-cut data like a multiple-choice test. There is tremendous global competition with PISA testing (Zhao, 2020). States want to keep the teaching methods the same if the assessment remains the same. Some states, like Virginia, have opposed education teaching method reform such as the CCSS (Watt, 2011). Additionally, national legislation (ESSA, 2015) places stipulations on how government funds are dispersed dependent on test scores.

Teacher Preservice Training and Professional Development

Collegiate teacher training programs instruct future teachers on learning taxonomies. The four learning taxonomies taught in higher education in America are Bloom's taxonomy of higher learning (1956), The structure of observed outcome (SOLO) taxonomy (Biggs & Collis, 1982), the depth of knowledge levels for four content areas (Webb, 2002), and Marzano's new taxonomy of learning objectives (Marzano & Kendall, 2006). The original six domains of higher learning in Bloom's taxonomy of educational objectives are in noun form (Bloom, 1956). The lowest level of learning is knowledge, followed by comprehension, application, analysis, synthesis, and evaluation, which is the highest level of learning. Bloom's taxonomy was revised in 2001 and listed in verb tense. The six levels of learning were changed to remember, understand, apply, analyze, evaluate, and create (Anderson et al., 2001). The SOLO taxonomy has four levels of complex learning, with the highest level requiring the learner to reflect, imagine, and create an untaught task application (Biggs & Collis, 1982). Webb's depth of knowledge also contains four levels of learning, with the highest level requiring the learner to plan, design, and create (Webb, 2002). Marzano's new taxonomy has four levels of learning, with the highest level being knowledge utilization, where the learner experiments, makes decisions, and problem-solves.

The common theme in all four taxonomies is that the pinnacle of learning encompasses creativity and innovation. Today, standardized summative assessments focus on measuring only if students remember and understand the content (Robinson, 2017). Teachers need to be trained to prepare students for Industrial Revolution 4.0, and to introduce students to 21st-century topics of virtual reality, augmented reality, and artificial intelligence (Teo et al., 2021). There is a desperate need to research how creativity and innovation can be implemented in a changing educational landscape.

A 2022 study recognized a project-based curriculum as the best way to implement 21st-century learning (Martinez, 2022). Training teachers on how they would teach in the future, such as using blended learning environments and student-centered instruction, also helped implement 21st-century learning (Senturk, 2021; Kesici & Cavus, 2021). Becoming a 21st-century educator requires formal and informal training, especially regarding pedagogical content knowledge (Love & Hughes, 2022; Shulman, 2013). Recent studies in China show that teacher self-efficacy in teaching STEM subjects is directly related to what this study focuses on: the lack of validated instruments of assessment (Chai et al., 2019; Nalipay et al., 2022). Moreover, if a creative educational harvest is a goal, educators must sew creative seeds through awareness, desire, and persistence (King & King, 2017). Educators must realize their positions of influence and passion for lasting and positive educational change.

While revising pre-service training is promising, 1.4 million secondary public school teachers are currently in the United States (Martinez, 2022). To train established educators, professional development training is needed. While professional development has shown to work well, there are not enough professional development opportunities to train every secondary teacher in the United States (Conradty & Bogner, 2020). Additionally, established teachers have reservations about teaching content and using tools and equipment they were never formally trained in. Integrative STEM professional development provides a great avenue to teach laboratory safety, promote collaboration within disciplines, and raise the self-efficacy of established teachers desiring to teach 21st-century curricula (Love, 2022). Integrative STEM education complements traditional instruction and focuses on higher-level thinking, specifically for students to create and encourages students to extend their learning.

School Guidance Counselors and Career Counseling

Curricular frameworks are only one thing that needs to be updated; the way students are counseled on future endeavors also needs to be revised. The fourth industrial revolution has brought numerous new types of employment to the workforce. Today, there are jobs in e-commerce, automation, robotics, artificial intelligence, digitalization, and data mining (Sims et al., 2020) that never existed when current career counselors were trained. New career opportunities will continue to evolve and expand, and it is paramount that guidance and career counselors use the 21st-century skill of creativity to introduce students to possible future employment paths (Valverde et al., 2020).

Educators play a significant role in why STEM classes and STEM careers are still dominated by males (Lv et al., 2022). There are stereotypical beliefs that males' perceptions of STEM disciplines are higher than females'. Lane et al. (2022) show that most stereotypes about women in STEM disciplines are untrue. Females have more positive perceptions of science than their male counterparts and show no distinguishable difference in perception toward STEM careers. Math is the only STEM subject in that males have higher perceptions and attitudes than females. Integrative STEM education has the potential to eliminate negative stereotypes and encourage learners of both genders to succeed in STEM careers.

Teacher Shortages

Positive educational change is less likely without the proper number of teachers. Teacher shortages create overcrowded classrooms or the elimination of course offerings. A noted technology education teacher decline has occurred since 1995 (Moye, 2009). Sometimes, industrial arts/technology education programs are dissolved simply because the teacher vacancy remains unfilled. The state of Virginia currently lists a top ten list of teacher critical shortage areas. Career and technical education, mathematics, and science education rank fourth, fifth, and sixth, respectively (VDOE, 2022).

Teacher shortages have forced numerous schools to hire teachers without formal teacher training. This means teachers are entering the classroom with varying degrees of content knowledge and no pedagogical or pedagogical content knowledge. Programs such as Teach for America (TFA) have emerged to recruit individuals to commit to teaching for two years in hard-to-staff public schools. TFA claims that 58,600 individuals have completed their two-year teaching stints in all 50 regions of the United States, including Virginia (TFA, 2022).

A 2020 student of average teacher pay ranks Virginia 28th out of 50 states in compensation with a $59,874 per year salary (VDOE, 2022). Michigan Technological University conducted a 2022 study of 18 different engineering careers. All engineering careers in the study have a mean starting salary of $58,500 or higher (MTU, 2022). Only two engineering careers, environmental engineering and geospatial science and technology, have a slightly lower starting pay than the average experienced teacher. Eleven of the eighteen engineering careers make an average salary of more than $100,000. Teacher retention is problematic when an individual with the skills to teach engineering design can easily make two to three times in the business sector. The change will not occur until government officials and taxpayers realize that teacher compensation, hiring and retaining quality, trained educators are investments in the future and the economy.

Flipped, Hybrid, and Online Learning

Technology and engineering teachers have always been forward-thinking. Technology education and industrial arts teachers created modular labs to introduce more appealing and exciting content to a wider variety of students (Harris, 2005). The modular technology education movement started in the 1980s. A typical modular laboratory focused on Grades 6-8 and consisted of 10-15 modules or learning stations, where students work independently or in groups of two on a design-based, problem-solving learning activity. Example modules include model bridge building and testing, rocketry, pneumatics, graphic design, computer-aided design (CAD), and robotics. Technology education majors are formally trained to facilitate modular learning. Positive outcomes occur when preservice teachers are trained in blended learning environments and require teachers to reflect on their learning (Senturk, 2020). For 21st-century learning to occur, preservice teachers must be trained in multiple learning environments.

There is no perfect learning environment. Modular laboratories' negative aspects are the high installation and upkeep costs, and teachers become bored from repeated facilitation of the same 10-15 design projects (Brusic & LaPorte, 2000). Modular technology changed how education was delivered to students. Modular technology required teachers to complete significantly more planning to create a more rigorous curriculum that motivated and engaged students (Harris, 2005). Technology teachers then became facilitators of the laboratory and relied on students' self-discipline to complete the learning module. Today, Canvas by Instructure is one of the most widely used learning management systems (LMS) in the United States (Nishitha & Pandey, 2021). Coincidentally, Canvas organizes its curriculum into learning modules. Online and hybrid learning caused a seismic shift in education and turned educators into facilitators who rely heavily on self-motivated students (Nishitha & Pandey, 2021). Distance and hybrid learning has yet to be perfected either, providing students with more opportunities for academic dishonesty (Harton et al., 2019). Non-technology and engineering educators should note how to facilitate design-based learning that focuses on higher-order thinking and increases student engagement.

In traditional instruction, students do what Robinson (2017) deems clerical work or taking notes. In a flipped classroom, the notes are recorded, and a student watches the lesson before attending class (Khan, 2012). The class time can then be used for creative projects and collaboration. Flipped classrooms hold the learner more responsible for their learning.

The fourth industrial revolution is characterized by interconnectivity. The interconnectivity is coined as the “Internet of Things” and describes how real-world physical items and digital items are connected through the Internet (Vermesan, 2022). Education is becoming a “one-world schoolhouse” (Khan, 2012). An internet connection can provide any student access to learning materials anywhere. If students worldwide have the same knowledge and skillset, those willing to work for a lower wage will be employed first (Zhao, 2012). The one-world schoolhouse concept and the forced shift to hybrid and online learning during the COVID-19 pandemic (Zhao, 2020) are why American schools must develop and implement a

21st-century curriculum. Technology and engineering teachers acknowledge that the COVID-19 pandemic brought the need to provide hybrid and distance learning options to technology classes that rely heavily on in-person, hands-on classes (Code et al., 2020). American students are losing jobs to foreign workers because they have the same basic knowledge and skillset. Foreign workers are willing to work for less compensation.

Assessment Challenges of Integrative STEM and 21st-Century Learning

Most teacher training programs utilize direct instruction. Direct instruction primarily uses lower-order summative assessments (Dubeck et al., 2021). The default method of assessment in the United States is testing. A student takes, on average, 113 standardized tests during their pre-K through 12th-grade career (Hefling, 2015). Multiple choice tests are currently the primary choice of assessment of knowledge. There is no standardized evaluation process for the four Cs of 21st-century learning.

Research has established over 100 ways to assess creativity since the 1950s (Sawyer, 2012). Some researchers debate whether creativity can be assessed (Blamires & Peterson, 2014). Mullen (2019) defines creativity as structured uncertainty. Others suggest a paradigm shift of assessing creativity by assessing the process, not the product (Shively et al., 2018). Producing a failed product but learning why the product failed should not result in a failing assessment. Zhao (2017) notes that drastic changes to the education system will cause some side effects, like those caused by new medicines. The side effects, or growing pains of assessing creativity, are signs of progress.

Integrative STEM instruction uses higher-order thinking and challenges students with open-ended, real-world problems. There is no one correct answer to a design problem. Typical summative evaluation of design-based projects includes rubrics and design portfolios (Kelley, 2011). There are inter-rater reliability issues in assessing STEM competencies and projects (Jang, 2016) and challenges in evaluating collaboration and critical thinking (Herro et al., 2017; Shively et al., 2018). Many teachers focus more on formative evaluations than summative ones, assessing the process more than the product. Kelley et al. (2019) note that 21st-century learners need to take a more active role in the assessment process and be able to reflect on what content and skills they have not mastered.

Additionally, teachers often question how to assess content from disciplines they are not an expert in (Haapaniemi et al., 2018). Lastly, teachers have difficulty assigning a group grade when group members exhibit an uneven workload. Assessing a group, not just an individual, requires the teacher to assess if the student learned the content and how the student collaborated with team members (Griffin & Care, 2015).

Summary

The American K-12 education system is not broken, but it is outdated. Every fragment of American culture has been subject to innovation over the last century, except in public education. The current K-12 curricular framework of teaching within isolated disciplines was established in the 1890s by the National Education Association (Mackenzie, 1894). The world was amid the Second Industrial Revolution in the 1890s; today, the world is currently in the Fourth Industrial Revolution (Pouspourika, 2020). American K-12 schools are still focused on high-stakes assessments (DeSilver, 2020). American schools need to improve upon the focus of teaching 21st-century learning using antiquated 19th-century methods. Research and educational stakeholders have shown a need to establish a 21st-century curriculum in American schools (ITEEA, 2020; ISTE, 2016; P21, 2009). Integrative STEM education is a viable option for teaching a 21st-century curriculum. It has numerous benefits, including technology and engineering educators collaborating with the sciences, arts, and humanities to solve real-world problems. The *STEL* (2020) is the curricular framework that guides integrative STEM teachers with eight practices of 21st-century literacy. However, little is known about teaching 21st-century literacy using the *STEL* as a curriculum framework and assessing 21st-century learning that is taught in an integrative manner. A gap exists in the literature on the risk of continuing to use traditional teaching methods versus implementing best practices for teaching 21st-century learning using 21st-century methods (González-Pérez & Ramírez-Montoya, 2022). This study attempted to fill the literature gap pertaining to integrative STEM curriculum and assessment of 21st-century learning by Virginia's 6th-12th grade technology and engineering teachers.

CHAPTER THREE: METHODS

Overview

This hermeneutic phenomenological study investigated the experiences of technology and engineering schoolteachers and their use of the *STEL* and integrative science, technology, engineering, and mathematics (STEM) methodology to foster and assess 21st-century learning in their classes. The eight practice goals of the *STEL* require students to evaluate and create. The ability to evaluate and create are the top two tiers of the hierarchy of learning (Bloom, 1956). The motivation for this study stems from the author's personal classroom teaching experience and desire to improve as a 21st-century educator. Procedures and methods for participant and site selection, data collection, and analysis are discussed within the chapter to allow for replication of the study. Data collection consisted of semi-structured interviews, journal prompts, and physical artifacts. The semi-structured interview questions for the individual interviews are provided. Methods for establishing trustworthiness, ethical considerations, and a chapter summary are also included.

Research Design

This qualitative study was designed as a hermeneutic phenomenology of technology and engineering teachers' perceptions and experiences with 21st-century learning. Qualitative research is "the use of interpretive/theoretical frameworks that inform the study of research problems addressing the meaning individuals or groups ascribe to a social or human problem" (Creswell & Poth, 2018, p. 42). I chose to do a qualitative study because I was interested in addressing the social and human problems of the antiquated compulsory education system. I chose phenomenology to investigate how technology and engineering teachers perceive and improve antiquated compulsory education through 21st-century pedagogical methods.

Personal experience is the starting point of phenomenological research (van Manen, 1990). The phenomenon explored in this study is 21st-century learning. Twenty-first-century learning focuses on Bloom's (1956) taxonomy of higher-order thinking, primarily synthesizing and creating. In empirical research, a qualitative hermeneutical phenomenology study allows participants to articulate their creativity as educators and synthesize how 21st-century learning occurs in their classroom. Phenomenological human science research is a form of writing (Van Manen, 1990). Van Manen (1990) notes, "Language is the only way by which we can bring pedagogic experience into a symbolic form that creates by its very discursive nature a conversational relation" (p. 111). The phenomenology research design was appropriate for this study because it provides the participant with three avenues to describe the essence of 21st-century learning using 21st-century pedagogy.

Hermeneutic phenomenology was chosen for this study because the researcher's experiences as a technology and engineering teacher are the driving force and inspiration to explore 21st-century learning further. Heidegger (1982; 1988) notes a researcher cannot avoid bias and bracket their experiences when conducting a hermeneutic study. The researcher served as this hermeneutic phenomenological study's primary data collection instrument. This study collected data by allowing participants to share their lived experiences as technology and engineering teachers through dialogue (the interview process), writing (journal prompts), and reviewing physical artifacts (lesson plans and curriculum development). I chose hermeneutic phenomenology as the research design to get unbiased perceptions of 21st-century learning from the teacher participants based on their experiences.

Research Questions

Central Research Question

What are the experiences of Virginia Technology and Engineering Teachers using integrative STEM methodology to implement the *Standards for Technical and Engineering Literacy* and foster 21st-century learning?

Sub-Question One

What are the experiences of Virginia Technology and Engineering Teachers about assessing the *Standards for Technical and Engineering Literacy* resulting from integrative STEM instruction?

Sub-Question Two

How do Virginia Technology and Engineering teachers using integrative STEM methodology develop a 21st-century curriculum based on experiential learning theory and the *Standards for Technical and Engineering Literacy* frameworks?

Setting and Participants

A hermeneutical phenomenological approach was used to explore STEM methodology and was conducted using 15 technology and engineering teachers from public secondary schools (Grades 6-12) in Virginia. The Commonwealth of Virginia offers 82 different technology education courses, ranging from grades K-12, in twelve subgroups: middle school technology, design and technology, entertainment design and technology, engineering, communications, technical design and illustration, electricity and electronics, production systems, power and transportation, principles of technology, biotechnology, and forensics (VDOE, 2022). The VDOE's goal for technology education classes is to develop technologically literate people who employ the technological processes of problem-solving, creating, and designing (VDOE, 2022).

Setting

Fifteen technology and engineering teachers (Grades 6-12) from the Commonwealth of Virginia participated in this study. During the 2020-21 school year, Virginia Public Schools employed 599 teachers endorsed in the Commonwealth in technology and engineering (T&E) (VDOE, 2022). The data does not stipulate where the 599 teachers teach. Virginia has 739 secondary schools that could offer technology and engineering classes: 310 high schools, 313 middle schools, 49 combined schools, 46 Career and Technical Centers, and 21 Governor's STEM Academies (VDOE, 2022). With 739 schools and 599 licensed teachers, the data shows that many schools do not employ a T&E teacher. Because numerous schools do not offer T&E courses or only have one T&E teacher, criterion surveys were offered to teachers who are members of the Virginia Technology and Engineering Educators Association (VTEEA, 2022).

Participants

Phenomenological qualitative research is conducted with a small number of participants. Polkinghorne (1989) suggests that researchers interview 5 to 25 participants who have experienced the phenomenon. The Liberty University School of Education requires a minimum of 10 participants to be interviewed for a qualitative dissertation. The criterion survey aimed to identify 10-20 individuals who are members of VTEEA, who currently teach technology and engineering education, with life experiences developing curricula that foster 21st-century learning. I felt saturation occurred after ten interviews, but I proceeded to interview five additional teachers because all 15 interviews were scheduled in a short time frame.

Teachers of all ages, ethnicities, and genders were encouraged to participate in this study. Yearly enrollment at varying Virginia secondary schools ranges from 40 to over 4,000 students and are grouped into six school size divisions. Teachers from five of the six school sizes participated in this study. Digital correspondence, including a criterion survey, was distributed to members of VTEEA to identify T&E members willing to participate in the study. Fully certified T&E schoolteachers hold an endorsement in technology education and may have a degree in engineering, engineering education, industrial arts, integrative STEM education, technology education, or career and technical education. After submission of the criterion survey, participants were asked to sign an acknowledgment of consent to be willing participants in this study.

Researcher Positionality

The motivation for this study stemmed from my 20-year career as a career and technical education (CTE) teacher using the STEL and integrative STEM methodology. I have spent numerous hours improving my craft of teaching and assessing 21st-century learning using interdisciplinary instruction in my classroom. This hermeneutical phenomenological study aimed to understand how other secondary school educators equip students with the skills necessary to prosper in the Fourth Industrial Revolution.

Interpretive Framework

The interpretive framework guiding this hermeneutic phenomenology is social constructivism. According to Piaget (1973), constructivism is constructing meaning from my lived experiences. I am a social constructivist and make no conscious hypothesis of the schema; my knowledge is built upon my human experience and interactions (Piaget, 1973). During this phenomenological research, my interactions with participants, through interviews, reading their journal prompts, and examining their physical artifacts, produced emergent theories from the participants' lived experiences (Creswell & Poth, 2018). Social constructivism is also known as interpretivism and depends upon me, the researcher, to interpret the data gathered and seek meaning in the world they experience (Creswell & Poth, 2018).

Philosophical Assumptions

My philosophical assumptions as a Christian researcher guide this study. I proclaim that God is the source and creator of all reality, knowledge, and values. Praise the Lord for his many blessings! The following paragraphs further explain my ontological, epistemological, and axiological assumptions.

Ontological Assumption

First and foremost, I proclaim to be a Christian researcher. My singular belief in the nature of reality is rooted in the truths presented in the Gospel of Jesus Christ documented in *The Holy Bible.* As a Christian researcher, I believe God creates and designs every person with an irrevocable set of gifts for a specific purpose (*New International Version*, 1984/2011, Romans 11:29). I also believe God only groups us into two groups: believers, and non-believers (*New International Version*, 1984/2011, Acts 17:26). Satan is the one who comes to destroy us by any means necessary (*New International Version*, 1984/2011, John 10:10), and seeks to cause division among groups (*New International Version*, 1984/2011, Romans 16:17-18). I believe everyone should have the opportunity to accept Jesus Christ as their Lord and Savior and equal opportunity for quality education.

Each person experiences different life experiences when answering God’s call. Life’s journey, coupled with revelations from God, produces unique perspectives from each person. While multiple realities will not be explored, exploring various perspectives and experiences is crucial to this study. This study utilizes the individual perspectives of 15 participants’ experiences to better understand the essence of fostering and assessing 21st-century learning in the classroom.

Epistemological Assumption

My epistemological assumption as a Christian researcher is that the fear of the Lord is the beginning of knowledge (*New International Version*, 1978/2011, Proverbs 1:7). Continuous knowledge acquisition directly correlates to a relationship with Jesus Christ. A relationship with the Lord will, in turn, produce wisdom (*New International Version*, 1978/2011, James 1:5). I acknowledge that some participants may not be Christians, and their assumption of knowledge may differ from mine. I will rely on my relationship with the Holy Spirit to guide me in data analysis, for the Lord gives me wisdom (*New International Version*, 1978/2011, Proverbs 2:6).

Axiological Assumption

The axiological assumption allowed me to ascertain my values as the sole researcher. As a Christian researcher, I believe God has a plan for all of us, a plan to prosper and not to harm us (*New International Version*, 1978/2011, Jeremiah 29:11). As a Christian researcher, I believe that God created us to do good things (*New International Version*, 1978/2011, Ephesians 2:10). God instructs us to strive for excellence in any endeavor (*New International Version*, 1978/2011, Ecclesiastes 9:10). God’s plan for me is to be the best teacher possible and prepare my students for prosperity empowering them with skills relevant to the current marketplace. I agree with the Aripin et al. (2020) educational taxonomy that states that learning about God is the highest level of hierarchal learning. This study aimed to discover how 21st-century learning can be better taught so schools can produce quality employees that drive the global economy. By doing so, students and educators will see that God has a plan for us all and desires us all to prosper and strive for excellence in all we set our hands to.

Researcher’s Role

I fully understood my role as a human instrument researcher (Creswell & Poth, 2018). I acknowledge that often, T&E teachers are isolated in their schools with no colleagues within their discipline to confer ideas. I have been isolated as a T&E teacher and offer this study to help others collaborate and communicate ideas for developing best practices of 21st-century learning in T&E classrooms.

I had no authority over any research participants in this study. All participants will be occupational peers; however, no acquaintances or friends will be part of this study. I openly acknowledge my internal bias as a T&E teacher that led me to pursue this study. I recorded and documented any potential bias or complications throughout data collection and analysis. The Virginia T&E teacher pool is a small, well-connected group. I excluded close friends from my criterion sample to avoid further bias or complication in my study.

Procedures

I am a Virginia Technology and Engineering Educators Association (VTEEA) member. The members-only section of the VTEEA website contains a list of 976 members of VTEEA from 2017 to the present (VTEEA, 2023). Once I gained approval from the Liberty University IRB, I utilized the VTEEA listserv to e-mail the 976 members of VTEEA to identify 15 technology and engineering teachers willing to participate in the study. After participants signed permission slips, I met participants individually for interviews. Interviewees were asked to provide copies of any physical documents they felt pertinent to their teaching of 21st-century learning. After the interviews, interviewees were asked to complete journal prompts. All three forms of data for triangulation were attempted to be collected simultaneously. Data were compiled and analyzed to identify common themes of teaching and assessing 21st-century learning.

Permissions

Approval from the Liberty University IRB was sought before seeking permission from any participants. After IRB approval, I sought consent from the elected board members of the Virginia Technology and Engineering Educators Association (VTEEA) in hopes of interviewing 10-20 candidates. Once 15 participants were identified, consent from each participant was obtained before data collection occurred.

Recruitment Plan

The sample size for this study was a criterion sample of 15 participants. Potential participants completed a criterion questionnaire administered via email. The requirements for participants in this study were to be a current member of the Virginia Technology and Engineering Educators Association (VTEEA), with a Virginia teaching license endorsed in technology and engineering education and currently teach in a Virginia Public Secondary School. Teachers must also acknowledge purposeful instruction of 21st-century learning using integrative STEM methodology and transdisciplinary, multidisciplinary, or interdisciplinary curricula in their classrooms. Upon selection, participants were sent a digital consent form acknowledging all participants were volunteers in this study and that no compensation would result from participating.

This study achieved triangulation by providing three data sources: journal prompts, individual interviews, and physical artifacts of the studied phenomena. Journal prompts were distributed before personal interviews. Responses were uploaded into the Delve data analysis software for analysis after all three data sources had been collected. Individual interviews were conducted via Zoom teleconference at a time and location suitable to the participant. With participant consent, interviews were audio recorded with the Delve data analysis software for later transcription. Transcripts were member-checked by each participant after each interview's completion and before the study's analysis phase. After each interview, participants were asked to share any physical documents they used to plan or assess the curriculum intended to purposefully teach creativity and innovation. All participants were asked to date each artifact to acknowledge how long they have used it in their classroom.

Data Collection Plan

This qualitative study is a hermeneutic phenomenology designed to explore teachers' perceptions and experiences of 21st-century education. The data collection for this study consisted of three types of data: individual interviews with technology and engineering teachers, journal prompts, and data from the teachers' physical artifacts. All three data sources are recommended forms of data for qualitative hermeneutic inquiry (Van Manen, 1990). All data were compiled into a digital log and analyzed with the Delve data analysis software.

Individual Interviews Data Collection

Consent forms approved by the review board were distributed to participants electronically via e-mail before the interview process. Individual interview protocol consisted of individual interviews via Zoom in a distraction-free setting (Creswell & Poth, 2018). A high-quality digital audio recording device was used. A series of open-ended interview questions listed below was used to guide the interview; however, the researcher allowed participants to direct the dialogue however they deemed necessary.

Individual Interview Questions

1. Please describe your educational background and career through your current position. RQ1
2. If not already stated, what professional development experiences or training(s) have prepared you to teach/facilitate 21st-century learning in your classroom? RQ1

For example, workplace or career readiness training, interdisciplinary or integrative education training, active classroom training, etc.

3. What are your perceptions and experiences of education outside of the single-discipline approach? What are your experiences with transdisciplinary (teaching content that relates to multiple disciplines), interdisciplinary (teaching content from multiple disciplines, STEM, STEAM, etc., but not necessarily taught using pedagogical content knowledge of each discipline), multidisciplinary (multiple teachers from across content areas working together) education, or integrative STEM education from your educational journey (both student and teacher)? RQ1

   For example, do you have any memories of learning math outside of math class or language arts instruction outside of English class? Did you experience this as a student or teacher?
4. As a 21st-century educator, do you create more interdisciplinary, transdisciplinary, multidisciplinary, or integrative STEM lesson plans? What are the major differences in your teaching practice compared to single-discipline educators? RQ1
5. Why do you think an interdisciplinary/integrative STEM curriculum paired with the STEL improves the capacity to properly teach 21st-century curriculum versus traditional single-discipline courses? Explain. RQ1
6. What is the hardest part of 21st-century education (STEL) to teach/facilitate? Explain.
7. What is the easiest part of 21st-century education (STEL) to teach/facilitate? Explain.
8. Describe the forms of assessment used in your classroom. Include assessments for class projects and any exit examination protocol for certifications or college credit. SQ1

9. How do you measure creativity as a learning output of interdisciplinary instruction/integrative STEM instruction? SQ1
10. How do you measure critical thinking as a learning output of interdisciplinary instruction/integrative STEM instruction? SQ1
11. How do you measure collaboration as a learning output of interdisciplinary instruction/integrative STEM instruction? SQ1
12. How do you measure communication as a learning output of interdisciplinary instruction/integrative STEM instruction? SQ1
13. How do you measure optimism as a learning output of interdisciplinary instruction/integrative STEM instruction? SQ1
14. How do you measure attention to ethics as a learning output of interdisciplinary instruction/integrative STEM instruction? SQ1
15. How do you measure systems thinking as a learning output of interdisciplinary instruction/integrative STEM instruction? SQ1
16. How do you measure making and doing as a learning output of interdisciplinary instruction/integrative STEM instruction? SQ1
17. How do you teach/facilitate content knowledge of a discipline when you are not currently an expert in that content area? SQ2
18. Describe the methods you use when you design an interdisciplinary/integrative STEM curriculum that focuses on higher-order thinking in your classes. SQ2

    For example, do you use active learning/active classroom, group learning, or project-based learning? Do you set up your classroom differently? Do you integrate a flipped classroom learning model? Do you integrate instructional technology in a new way?

19. What else would you like to add to our discussion of your experiences with 21st-century learning (STEL) or integrative STEM methodology? SQ2

Individual Interviews Data Analysis Plan

For this study, data was analyzed by thematic analysis derived from hermeneutic phenomenological theory (van Manen, 1990). Van Manen (1990; 2016) states that the goal of hermeneutic phenomenology is to discover the essence of a phenomenon; the essence is discovered by further inquiry into participants' lived experiences. This further inquiry requires stages of thematic analysis. The stages of data interpretation are review, primary themes, sub-themes, synthesis, and integration (van Manen, 1990).

All data collected via interviews was transcribed into the Delve data analysis software. The review stage requires initial and holistic coding (Saldana, 2013). Van Manen (2016) suggests researchers first analyze the entirety of the data and code themes holistically with one central idea. Primary themes repeatedly appear in the transcript (van Manen, 1990). Van Manen (2016) suggests the second analysis round uses selective transcript readings to categorize themes into sub-themes. For this study, the second round of coding focused on causation coding and versus coding (Saldana, 2013) to identify and sort 21st-century education themes into categories. Van Manen (2016) suggests the third round of analysis to be a detailed reading approach or synthesis of sub-theme data. Each line of text will be read to examine if a theme can be grouped or sub-grouped with the established coding done in the first two rounds of analysis. The data gained analyzing the individual interviews was used in triangulation with the data from the physical artifacts and the journal prompt responses to identify and create a textural representation of how 21st-century learning is fostered in Grades 6-12 technology and engineering classes.

Journal Prompt Data Collection

At the end of the interview process, participants reflected on their responses and clarified and expanded their explanations by writing the journal prompts. Journal prompts were provided to participants via email using Google Forms. Data from the journal prompts was collected on the same day of the individual interviews. One participant failed to submit their journal prompt. The journal prompt data from Google Forms was compiled into a Google Spreadsheet that was later analyzed using the Delve data analysis software. The journaling data collection had four prompts with a minimum response of two paragraphs.

Journal Prompt One

Describe how you purposefully design an integrative curriculum that aligns with the STEL to foster higher-order thinking and skills needed in the 21st-century workforce.

Journal Prompt Two

Describe how you assess students' 21st-century learning: the eight STEL practice goals of creativity, collaboration, critical thinking, communication, optimism, making and doing, systems thinking, and attention to ethics.

Journal Prompt Three

Describe your educational path to becoming an interdisciplinary/transdisciplinary/integrative STEM teacher.

Journal Prompt Four

Explain your methods of teaching and assessing content in which you have varying levels of content knowledge, subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge.

Journal Prompts Data Analysis

Van Manen (1990) stresses the importance of silence in the hermeneutic phenomenological process in both the interview and reflection writing. Van Manen (1990) does not view silence as a lack of understanding but as the opportunity to pause for deeper reflection. Creswell and Poth (2018) note that journal prompts allow participants to review their answers to provide further clarity on their lived experiences. The journal prompts were instructed to be completed after the individual interview process to enable the participant to reflect and adjust answers to interview questions as needed to uncover a deeper understanding of their lived experiences.

The journal prompts and the individual interviews were analyzed in the same fashion. The only difference is the journal prompt data was initially focus-coded (Saldana, 2013). Because the journal prompts were completed after the interview process, focus coding is used to establish frequent and significant codes that can be used for further rounds of analysis. The journal prompts were analyzed using van Manen's (2016) three-stage method of holistically coding the entire document, coding selected passages, and coding line-by-line. Holistic coding is broad coding used to identify major themes readily apparent in the data. Coding selected passages is also called in-vivo coding and is the process of splitting data into codable moments. Lastly, line-by-line coding will be done to analyze all data. A codebook was kept in the Delve software that organized major themes, definitions, and emergent codes. In addition, to focus coding, causation coding and versus coding were done to identify what causes the fostering of creativity and innovation and which methods had better success rates.

Physical Artifacts Data Collection

After gaining permission to use teacher documents (Marshall & Rossman, 2006), teachers participating in the study provided physical documents that record a learning outcome or curriculum planning to develop 21st-century learners. Van Manen (1990) notes that any document can record the lived experience of a participant. Because technology and engineering teachers possess different PCK than teachers of other disciplines, their lesson plans and assessments are often vastly different from their teaching colleagues. Physical artifact data collection allowed the researcher to thoroughly examine each educator's creativity and innovation. This study examines lesson plans, formative and summative assessment tools (rubrics, certification exams, project descriptions, worksheets, etc.), educational websites that show digital copies of lesson plans and assessments (teacher portfolio websites, Google Classroom websites, and Canvas class websites), Virginia curriculum competency records and standards for each career and technical class being taught, notes, drawings, sketches, diagrams, assessment guidelines, or any other pertinent artifact used in the process of 21st-century learning.

Physical Artifact Data Analysis

Analyzing physical documents allows the researcher to view the reflective process of the participant (Heidegger, 1962). Friesen et al. (2012) claim that teachers are naturally hermeneutic phenomenologists, consistently in a cycle of theory, practice, and reflection. For this study, document analysis focused on how participants specifically recorded the process of fostering creativity and innovation in their classroom using interdisciplinary and transdisciplinary approaches. Doing so allowed the researcher to interpret documented action steps completed by the participant in addition to the explanation of their lived experience.

Each participant was asked to provide physical artifacts they used to foster 21st-century learning in their classrooms. Participants were asked to date each artifact submitted so they could be longitudinally coded (Saldana, 2013). Suggested artifacts include, but are not limited to, lesson plans, formative and summative assessment tools (rubrics, certification exams, project descriptions, worksheets, etc.), educational websites that show digital copies of lesson plans and assessments (teacher portfolio websites, Google Classroom websites, and Canvas class websites), Virginia curriculum competency records and standards for each career and technical class being taught, notes, drawings, sketches, diagrams, and assessment guidelines. The analysis aimed to explore how planning for creativity, critical thinking, collaboration, communication, and cultural and character education happens beyond the written word and to examine how the experiences of the phenomena developed over time. Each artifact was labeled and digitally entered into the Delve data analysis software. All documents were analyzed sequentially by date, otherwise known as longitudinal coding (Saldana, 2013). Longitudinal coding allowed the researcher to view each participant's natural reflective hermeneutic research to provide a better textual description of the phenomena.

Data Synthesis

All data compiled during the inquiry process was uploaded to the Delve data analysis qualitative software. This software allowed for data triangulation and audio transcripts, journal prompts, and physical documents to be assembled and synthesized in one place. All participants received a copy of their transcription for validation before the coding process began (Creswell & Poth, 2018). First-cycle coding (holistic, initial) and second-cycle coding (longitudinal, sub-coding) were conducted (Saldana, 2013), which produced a word cloud in the Delve data analysis software. The word cloud synthesized and reduced individual themes to identify the major themes of the study. The synthesis stopped when saturation occurred, and no new insights were presented in the data. The researcher balanced the synthesis of the parts and the whole interviews to compile a "story" of the participants' lived experiences (van Manen, 1990). This story was then compiled into a textual representation of fostering and assessing 21st-century learning in Grade 6-12 technology and engineering classes.

Trustworthiness

Lincoln and Guba (1985) have established criteria for rigor, standards, and objectiveness regarding trustworthiness in qualitative research analysis. Trustworthiness in qualitative research is established by asking questions relevant to credibility, transferability, dependability, and conformity to verify the reliability of the study (Lincoln & Guba, 1985; Patton, 2015). This section describes the criterion and process to establish trustworthiness in qualitative research devised by Lincoln and Guba (1985).

Credibility

A study is credible when the research findings are true and accurate (Lincoln & Guba, 1985). Seven techniques are used to establish credibility in qualitative research semi-structured interviews. This study was credible because I conducted formal semi-structured interviews with an interview guide listing the open-ended questions. The interviewee was free to express their views however they felt appropriate. The interviews were recorded, and the interviewer refrained from taking extensive notes during the interview. The interview was transcribed and entered into data analysis software to provide comparable qualitative data (Cohen & Crabtree, 2006). Additional measures to establish credibility for this study include triangulation and member-checking, which are explained below.

Triangulation

Triangulation is the technique of using three different data sources of a phenomenon to develop a comprehensive understanding of the phenomena being studied (Cohen & Crabtree, 2006). In this study, triangulation was accomplished using the data from journal prompts, individual interviews, and physical artifacts of the participants. Triangulation of data focuses on each participant's lived experience, makes sense of possible disparate data between participants, and establishes a chronological flow of how each participant experienced the phenomenon.

Member-Checking

Member-checking allowed participants to validate the transcriptions of their interviews and artifacts provided for research (Cohen & Crabtree, 2006). The process of member-checking is essential in this hermeneutic phenomenology study because I am the sole researcher and did not bracket my bias. I desired to provide an audit trail to establish confirmability. The member-checking process provides evidence the researcher did not bully, change, or manipulate answers from participants (Marshall & Rossman, 2006).

Transferability

Transferability shows the reader the study's findings may or may not apply to other situations (Patton, 2015). The transferability process relies on thick descriptions of research findings (Geertz, 2008). The researcher cannot guarantee transferability. The researcher can only provide thick descriptions of the research findings, allowing the reader to acknowledge the study's transferability (Creswell & Poth, 2018).

Dependability

Dependability is established by providing research findings that are consistent and can be replicated (Lincoln & Guba, 1985). A dependability audit will be conducted by the researcher’s committee members at Liberty University during the dissertation process to ensure data is correctly collected, maintained, and accurate. Additionally, the researcher will perform a self-audit before publication and keep all research documents and data locked, secure, and confidential.

Confirmability

The researcher is a technology and engineering teacher who uses integrative STEM methodology to foster and assess 21st-century learning in his classroom. While conducting this hermeneutic phenomenology study, the researcher acknowledges their personal experiences may produce bias. By acknowledging potential bias, the researcher entered all data into the Delve data analysis software and provided an audit trail to show personal experiences and beliefs do not interfere with the study (Lincoln & Guba, 1985). Further neutrality in data collection, analysis, and synthesis was established by triangulating data from journal prompts, individual interviews, and participant personal artifacts.

Ethical Considerations

Marshall and Rossman (2006) note the prominent ethical issues dealing with data collection about the setting and participants, explicitly protecting the anonymity of participants and securely storing all research data. While the researcher's biases directed and created the semi-structured, open-ended interview questions, the researcher used silence to allow participants to respond at their own pace (van Manen, 1990). The interview process aimed to hear the participants' lived experiences, not to answer guided questions led by the researcher's biases. Participants agreed to consent forms before the interview and chose the Zoom interview time. Pseudonyms are used for all participants. Confidentiality of the site and the participants occurred throughout the study. Participants were reminded they were volunteers and may skip specific questions or withdraw from the study at any time (Marshall & Rossman, 2006). To ensure the anonymity of the participants, all data used in this study are securely stored in locked office spaces and password-protected. I plan to keep the data because I, the researcher, plan to study further the topics of 21st-century learning and integrative STEM methodology.

Summary

Chapter Three clarifies the design, research questions, setting, participants, procedures, the role of the researcher, data collection, data analysis, trustworthiness, and ethical considerations of this hermeneutical phenomenological study aimed at better understanding how creativity and innovation are fostered in Virginia public secondary schools. This research utilizes Van Manen's (1990; 2016) hermeneutical phenomenological research design. Triangulation of data collected occurred using journal prompts, individual interviews, and physical artifact collection. Data analysis was completed using Delve data analysis software. The Liberty University IRB monitored this study. This study was proven trustworthy by establishing credibility, dependability, conformability, and transferability. All ethical considerations established by Liberty University policy were followed.

CHAPTER FOUR: FINDINGS

Overview

The purpose of this hermeneutic phenomenological study was to understand the perceptions of Virginia Technology and Engineering Teachers using integrative STEM methodology to implement the *STEL* to foster 21st-century learning. This chapter includes participant descriptions, data analysis in narrative themes, outlier data, and research question responses.

Participants

I distributed a research recruitment letter to over 800 Virginia Technology and Engineering Educators Listserv members. After waiting ten days, the listserv recruitment email did not provide the minimum number of participants for research validity. I then contacted 107 teachers through individualized emails to continue the recruitment process. Fifteen educators responded, completed consent forms, and were interviewed over five weeks. All participants shared physical artifacts for data collection, and fourteen participants completed journal prompts. The participants returned their consent forms before the individual interview. Participants were assigned pseudonyms, and a description of each participant is listed below.

Gaspar

Gaspar is a career technology and engineering teacher with 28 years of experience, primarily teaching Grades 9-12. Gaspar has a bachelor's degree in technology education and a master's degree in STEM leadership. Gaspar's area of expertise is facilitating design-based, engineering-design projects that address real-world problems.

Tubal Cain

Tubal Cain has 6 years of technology and engineering teaching experience, primarily teaching Grades 9-12. Tubal Cain is a career switcher with over twenty years of experience working elsewhere. Tubal Cain has a bachelor's degree in psychology, a master's degree in international relations, and a Doctor of Education in leadership and learning. Tubal Cains's areas of expertise are robotics, engineering, and design.

Eunice

Eunice is a former business teacher with six years of experience teaching Grades 6-8 technology education. Eunice has a bachelor's degree in graphic design, and a master's degree in software engineering, with an endorsement to teach technology education. Eunice's areas of expertise are graphic design and workplace readiness skills.

Luke

Luke has 12 years of technology and engineering teaching experience, teaching both at the middle and high school levels (Grades 6-12). Luke has a bachelor's degree in agricultural education, a master's degree in career and technical education, and a doctorate in educational leadership. Luke's area of expertise is facilitating design-based, engineering-design projects that address real-world problems.

Shaphan

Shaphan has 14 years of technology and engineering teaching experience, spending his entire teaching year teaching Grades 9-12. Teaching is a second career for Shaphan after spending over two decades working in industry. Shaphan's areas of expertise are technical drawing, architectural drawing, and computer-aided design.

Huldah

Huldah is a career technology and engineering teacher with 20 years of experience teaching both at the middle and high school levels (Grades 6-12). Huldah has a bachelor's degree in technology education and a master's degree in educational leadership. Huldah's areas of expertise are technical and architectural drawing, engineering design, and problem-based learning.

Bezalel

Bezalel is a career technology and engineering teacher with 29 years of experience teaching both at the middle and high school levels (Grades 6-12). Bezalel has a bachelor's degree in technology education. Bezalel's areas of expertise are manufacturing, materials and processes technology, and anything involving a traditional industrial arts fabrication laboratory.

Nehemiah

Nehemiah is a career technology and engineering teacher with 23 years of experience, primarily teaching Grades 9-12. Nehemiah has a bachelor's degree in technology education and a master's degree in technology education. Nehemiah's areas of expertise are robotics and STEM engineering.

Shem

Shem is a former mathematics teacher with two years of experience teaching Grades 6-8 technology education. Shem has a bachelor's degree in mathematics education, with an endorsement to teach technology education. Shem's areas of expertise are facilitating collaboration and critical thinking.

Miriam

Miriam has 14 years of technology and engineering teaching experience, primarily teaching Grades 9-12. Miriam is a career switcher after a brief stint working in industry. Miriam has a master's degree in technology education. Miriam's areas of expertise are technical drawing and architectural drawing.

Simon

Simon is a former elementary teacher with five years of experience teaching Grades 6-8 technology education. Simon has a bachelor's degree in elementary education, with an endorsement to teach technology education. Simon's area of expertise is robotics.

Ezra

Ezra has 14 years of technology and engineering teaching experience, primarily teaching Grades 9-12. Ezra is a career switcher with fifteen years of experience working in industry. Ezra has a bachelor's degree in electronic media, with an endorsement to teach technology education. Ezra's areas of expertise are communication technology and electronics.

Oholiab

Oholiab is a career technology and engineering teacher with 22 years of experience, primarily teaching Grades 9-12. Oholiab has a bachelor's degree in technology education. Oholiab's areas of expertise are photography, materials and processes technology, and architectural drawing.

Nathanael

Nathanael has 17 years of technology and engineering teaching experience, teaching both at the middle and high school levels (Grades 6-12). Nathanael is a career switcher with a brief career working in industry. Nathanael has a bachelor's degree in computer science, and a master's degree in school administration, with an endorsement to teach technology education. Nathanael's areas of expertise are game design and computer science.

Ruth

Ruth is a career technology and engineering teacher with 33.5 years of experience, primarily teaching Grades 6-8. Ruth has a bachelor's degree in industrial technology education and a master's degree in education. Ruth's areas of expertise are engineering by design and architectural drawing.

Table 1

Teacher Participant

Teacher participant	Years' experience in T & E	Highest degree	Content area	Grade level
Gaspar	28	Masters	Technology Education	9-12
Tubal Cain	6	Doctorate	Technology Education	9-12
Eunice	6	Masters	Technology Education	6-8
Luke	12	Doctorate	Technology Education	6-12
Shaphan	14	Bachelors	Technology Education	9-12
Huldah	20	Masters	Technology Education	9-12
Bezalel	29	Bachelors	Technology Education	9-12
Nehemiah	23	Masters	Technology Education	9-12
Shem	2	Bachelors	Technology Education	6-8
Miriam	14	Masters	Technology Education	9-12
Simon	5	Bachelors	Technology Education	6-8
Ezra	14	Bachelors	Technology Education	9-12
Oholiab	22	Bachelors	Technology Education	9-12
Nathanael	17	Masters	Technology Education	9-12
Ruth	33.5	Masters	Technology Education	6-8

Results

This section includes the analysis of the data collected from individual interviews, physical artifacts, and journal prompts. The pedagogical approach to the eight practices of technology and engineering teachers outlined by the *Standards for Technological and Engineering Literacy,* integrative STEM methodology, and measurement of 21st-century learning are discussed. This section also articulates how Virginia Technology and Engineering teachers develop 21st-century curricula.

Practices of Technology and Engineering Educators

All fifteen teachers interviewed agreed that the eight practices of technology and engineering teachers defined by the *STEL* were the foundation of teaching and learning in their classrooms. Teachers noted that integrative STEM methodology was utilized as the primary means of instruction by choice and necessity. Huldah identified as a "singleton," meaning she was the only technology education teacher in her school building. Nehemiah noted a neighboring school was "built around that whole group teaching philosophy," but generally speaking, technology and engineering teachers are an isolated group. The description of the different schools in this study were vastly different, and many teachers agreed they would like to utilize multidisciplinary design-based learning, but there were numerous barriers (scheduling, staffing, classroom availability, etc.) preventing collaborative instruction.

Integrative STEM Methodology

All teachers in this study acknowledged that integrative STEM methodology was an integral part of their instruction. Integrative STEM education is the purposeful instruction of multiple disciplines to solve problems. Nathanael took a competency-based educational approach to integrative STEM methodology and said, "I try to take what they are learning in other classes and have them apply it with the content they learned in here." Tubal Cain noted that his priority was to demonstrate to both students and fellow teaching faculty that integrative instruction was occurring in the building, stating, "What I'm focused on now at school is taking our engineering courses out of our corner of the building and building a stronger connection with physics, with biology with the math department, so that the students are beginning to see these don't exist in a bubble." All teachers agreed that technology and engineering curriculum is enhanced when other disciplines are incorporated into problem-based, design-based instruction.

Creativity

Teachers overwhelmingly agreed that creativity has as many ambiguous definitions as the word "technology" and provided several great definitions. Shem stated, "To be creative, one must try something new." Ezra echoed Shem by saying, "Creativity often produces something never seen before." Gaspar elaborated more on creativity by stating, "Creativity is proportionate to time and effort. Creativity is produced when learners go beyond the minimum that is asked of them. I purposefully allow for individuality and out-of-the-box thinking in my lessons/projects." The *STEL* (ITEEA, p. 75, 2020) references the NEA (2019) that creativity occurs while thinking, working with others, and innovating. Creativity is a process, experience, and product that results from being competent in multiple practices of the *STEL*.

Critical Thinking

Teachers identified critical thinking as the *STEL* practice in which 21st-century learners ranked lowest in competency-based assessments and was the most challenging practice to teach. Nathanael said, "Critical thinking, that's something that I've noticed is lacking with students." Shem responded, "Critical thinking and problem-solving is the most difficult thing to teach them to do. Because it's teaching them how to think for themselves." Oholiab explained that students who excel in traditional education are adept at lower-order thinking skills, such as listening and following instructions. Critical thinking is foundational to higher-order thinking. Ruth added, “I don’t think you can problem solve without critical thinking.” Shaphan said, “I want you to start thinking. That's where the critical thinking part comes into play. I don't want to tell you how to do everything.”

Collaboration

Teachers noted that collaboration was a pedagogical priority in integrative STEM classrooms. Luke stated that he requires all projects to be done in groups of 2-4 students. Eunice explained that forced collaboration prepares students for postsecondary employment by noting, “By fostering an environment where students routinely engage in cooperative problem-solving, idea exchange, and teamwork, I enable them to harness the power of diverse perspectives and develop the interpersonal skills crucial for modern workplaces.” Ruth had creative ways of viewing collaboration, explaining that professionals must collaborate even in seemingly solitary positions, stating, “I invited experts into my classroom. I am constantly looking for new ways and different ways to do things. I use my resources. I have found experts on YouTube.” Ruth models to her students that collaboration is not geographically restrictive. If you and others near you cannot solve a problem, find someone in the constantly connected world who can collaborate with you.

Communication

Teachers agreed there were numerous types and methods of communication, and students needed to articulate thoughts, actively listen to others, and engage in constructive dialogues. No universally accepted preferred method of communication was identified in this study. Bezalel explained he measured a student to be competent in communication by how well they work with others. Making and doing with collaboration is only possible with competent communication. Bezalel added that planning/brainstorming is vital for communication between students and teachers, saying, "I show them how to make a project plan, a basic sketch of what they're building. If they can't even visualize what they want to make, it kind of tells me they don't really have a good idea of what they're going to make." Eunice added that communication goes beyond articulating a plan; an excellent communicator must be adept at managing conflict. Miriam said that the repercussions of COVID-19 school scheduling forced many students to hurriedly learn the basics of electronic communication. Miriam also stated the return to regular school schedules required reviewing how to share tools properly and waiting for turns in a fabrication lab.

Attention to Ethics

Teachers agreed that practicing attention to ethics was a multi-faceted process. Teaching ethics is far more than reviewing an honor code; Shem noted:

> "Of course, in school, you know, we all have, we have our honor codes. Don't cheat, don't lie, don't steal, don't plagiarize. You know, every school has those. But I like to investigate breaks of breaches of ethics and history and historical context. Many people say a lot of research supports the idea that Edison stole design ideas from Nikola Tesla, Marconi, who created the radio, somebody copied his invention designs, and then I think there was a court case about that, too. So, I like to investigate the historical precedence of ethics and technology. But I also like to explain and teach them that, you know, inspiration and learning from others is not a breach of ethics. Ethics is a problem when we don't help somebody, or we copy somebody else's work, and we take it for our own. I like to teach them that, you know, I can draw inspiration from other things."

Miriam responded that teaching ethical behavior corresponded to preparing students for the future workforce by adding, “Ethics is a topic that we spend time discussing! Not only ethics in the classroom but the ethical responsibility of becoming a licensed engineer!” Ethics is learning responsibilities and that all our actions have consequences.

Optimism

Teachers noted that teaching optimism was also viewed with ambiguity. Shem stated many ways of teaching optimism, saying he taught “optimism about their grades, optimism about their performance, and about their projects.” Ezra maintained that optimism focused mainly on engineering design, stating, “In engineering, you learn by failure, and optimism is continuing the design.” Miriam noted, “Optimism is I want the kids to know that failure is okay, like when you design something, it's not going to be perfect every time.” Eunice associated optimism with being technologically literate. Eunice stated, “I can’t be an expert in everything.” Explaining optimism is needed for lifelong learning; technology will evolve, and optimism is needed to learn new technology continually.

Systems Thinking

Systems thinking can be simplified as the cyclical process of input, processes, output, and feedback. Systems thinking contrasts significantly with traditional education, which typically progresses linearly. Ezra explained that students often view a final exam as a finish line, and knowledge only must be retained until the end of the course. Systems thinking establishes a mindset of constant improvement and innovation. Miriam said, “For systems thinking, I have students use flowcharts and the engineering design process to invent and innovate designs!” Shem noted that feedback was crucial to continual learning, stating that systems thinking was taught collaboratively in his class by “getting feedback from other people, and then we're making changes accordingly.”

Making and Doing

All Respondents replied that making and doing was the defining pedagogical characteristic of technology and engineering education. Shaphan explained that tactile learning was his classroom's primary learning medium: "Everything I do is hands-on. Where in a lot of the other classes, you know, it's not necessarily hands-on.” Ruth explained that making and doing can be unit-based, project-based, or design-based learning. Students make and do not only to solve problems but to foster deeper learning. Making and doing goes beyond acquiring knowledge to learn and then applying skills and abilities. Eunice explained that making and doing allows students to “apply theoretical concepts to real-world scenarios” and “acquire domain knowledge and learn inquiry, research, and problem-solving skills.” Nathanael responded that making and doing was how he made learning fun in his classroom, and often making and doing was done by “gamification.”

Measuring 21st Century Learning

A 21st-century learner must be knowledgeable, competent, and technologically literate: knowledgeable to pass a multiple-choice test, competent to foster higher-order thinking and lasting learning, and technologically literate to know how to solve problems. Teachers are expected to measure competency in learning while using antiquated assessment methods. While student assessments are shifting to competency-based systems, Ruth stated, “We have to give pre and post-tests for evaluation purposes on us, which I absolutely abhor.” Students are comfortable using tests as the only means of assessment. Eunice said students “want to be tested; they want to show me that they know what they're doing.” Gaspar eliminates tests from his curriculum and focuses on the eight practices of the *STEL.* Gaspar noted that students tell him he is "making them think too much" and that "this is too hard." Shaphan replied that 21st-century learning is more than memorization and being competent in the eight *STEL* practices. Shaphan said students need to be technologically literate, and "The object is knowing where to go look for the answer."

Rubrics

Rubrics are the primary form of summative assessment for students in technology and engineering classes. Nehemiah explained a rubric was a "checklist of requirements for completion that lessons the subjectivity in the grading process." Ezra replied that he has four types of rubrics in this class, "a presentation rubric, collaboration rubric, engineering notebook rubric, and a technical writing rubric." Luke added, "I provide rubrics for all formative and summative assessments. Assessments are criterion/competency-based, meeting the alignment with the VDOE standards." Bezalel responded that he also uses a rubric for laboratory clean-up grading. Rubrics are the way technology and engineering educators document and justify the letter grade awarded to each student.

Self-Assessment

Traditional assessments are finite. There are only so many ways to give a test. Self-assessment is a paradigm shift because it causes students to look inward and provide themselves with feedback. By learning the fundamentals of design thinking, students realize there is always room for improvement, thus providing limitless opportunities for growth and learning. Gaspar requires students to enter a daily log in their engineering notebook as a formative self-assessment. Ruth replied, "The engineering notebook also serves as a good way to document progress or use of the *STEL*." Simon explained that self-assessment was an excellent way to teach attention to ethics. Simon starts the self-assessment process by asking, "How do you think you did today? What would you like to improve on? What do you think was a great success? What do you think? What did you struggle with the most?" Simon continued, "That hits them differently because they, you can tell first, they're not honest because they realize their project grade will be low if they are sincere. I get better grades if I can twist those dials, give myself a little shine, and make myself look fresher. And they do. But by the end, I see a lot more honesty, which is important because I tell them all the time, "I can't grade how I think you're doing if you're lying to me about your progress."

Academic Systems Thinking

Abundant feedback is available when teaching and learning: positive, negative, oral, written, self, collaborative, peer, descriptive, and evaluative. All teachers in this study were interested in answering the questions, "How do I improve my output? How do I become a better teacher?" Numerous participants noted the value of professional development, specifically from other technology and engineering educators, to improve as a teacher. Teachers pointed out that peer feedback was unavailable for most of the school year. The bulk of feedback, which comes in all forms, comes from students. Miriam replied that she "learns with her students." Nathanael noted, "It's almost sad to say I am outdated, but many teachers are. I have students who teach me stuff here because they find different ways of solving the same problem or something updated." Ezra felt compelled to teach students new technology that he was not an expert in by stating, "I'm not a super expert on this. So, we're going to go slower; you're going to do a lot of reading at the beginning, a lot of exploring and discussing each class member's experiences with this topic." Technology and engineering teachers constantly analyze feedback to decide which inputs and processes will improve academic output.

Developing 21st Century Curriculum

Twenty-first-century curriculum produces technologically literate students with the knowledge, skills, and abilities to solve problems. "One important defining feature of technological and engineering literacy is the emphasis on process and action, including design and making." And this is the "literacy needed to solve our most pressing societal needs." (ITEEA, 2020, p. 2). The teachers in this study perceived their classes as the only place in their respective schools where technological and engineering literacy were being taught. Several teachers asked, "How are people expected to do things they have never been trained in? Specifically, how are people supposed to solve problems in the real world if they are never taught to solve problems in school?" Nehemiah said, "I always kind of relate things to the real world. I'll work backward, I'll kind of come up with what needs to be taught, and kind of develop into an activity I can do in the classroom." Oholiab explained he is more than a tool trainer, "I always tell my students that everything I use in my classrooms is a tool. I'm not here to teach you specific software. You learn the software to apply and solve real-world create or innovate." Shem, a middle school teacher, uses a process he calls "I do, we do, you do" for younger students, enabling them to observe his problem-solving techniques, work with him, and then branch off and solve a problem independently. Creating a curriculum for 21st-century learners reinforces the need for integrative STEM methodology and the eight practices of the *STEL* to be taught universally. Every piece of knowledge, skill, or ability in every discipline can be used as a tool to solve real-world problems.

Workplace Readiness Skills

Every teacher in this study mentioned the importance of workplace readiness skills (WRS) to 21st-century learning. The WRS are the first 22 competencies included in all 82

technology education courses in Virginia Public Schools. Huldah replied the WRS are a great way to introduce the eight practices of the *STEL*. Those things [the eight practices] tie into the workplace readiness exercises that I do, and then follow over them and develop into the class projects that we have." Eunice echoed the importance of experiencing the WRS, "You can't just talk about workplace habits. You must let them have those experiences." Ezra simplified the WRS by saying," There are deadlines in the real world. You have to work with people."
Tubal Cain expressed frustration with post-pandemic administrators establishing contradictory policies to the WRS, such as eliminating due dates for student work, by saying, "There is always just the metric of "Did you get it done on time?" And I think that's one of the toughest things right now." Nathanael uses the WRS to contradict the philosophy that a student needs a college degree to succeed:

> "You don't have to have a degree to make money. And that's a that's a big one. Go out to the workforce and work your way up. That's why you must learn workplace readiness skills; that's your customer service skills. Your creativity is what's going to make you money because everybody in the world is now on the same playing field [referencing access to basic knowledge]."

Learning to be professional, solve problems, and collaborate are skills needed for success in the 21st century.

The Design Process

The engineering design loop has a critical step: improve/redesign. The American educational system has had minimal improvement or redesign in 130 years. Teaching and learning are iterative processes. The systems thinking model (input, process, feedback) and the engineering design loop can be used to show how teaching and learning are never-ending processes. Bezalel explained that technology education was continually changing, “When I started, nobody talked about 3D printers; we never heard of it. We learn to teach about them, and new stuff is coming out, it's evolving.” The experiences of technology and engineering teachers and learners should provide feedback to show that implementing the design process can potentially improve the American educational system.

Outlier Data and Findings

Before data collection, I assumed all pedagogical teaching methods of technology and engineering educators could be identified as one of the eight practices outlined in the *STEL.* All fifteen participants responded that the eight practices (creativity, collaboration, critical thinking, communication, attention to ethics, systems thinking, optimism, and making and doing) were integral to 21st-century education. However, the individual interviews identified two other teaching practices as vital to 21st-century education.

Empathy

The world has an almost endless list of problems to solve. The National Academy of Engineering (2023) lists 14 grand challenges that are still unsolved. Gaspar tells this to his students, “I tell them in the real world, people don't care what you know, they care what you do for them.” Gaspar explained that people do not want to understand you. They just want their problems solved. To solve their problems, you must understand them. Gaspar continued, “When a person comes to you with a problem, they usually point out a symptom, not the actual problem. By being empathetic and asking questions, you can start going deeper and deeper. So you can nail the problem on the head. It's empathy, you know, getting to really understand their problem.” Empathy allows students to create meaningful and actionable problem statements for their design projects. Gaspar said, “Ultimately, I tell my students STEM is not what you know; it is what you do with what you know.”

Preparation for the Unknown

Numerous teachers in this study responded and noted the significant changes in the technology and engineering education profession over the last three decades. Several teachers reported the initial printing of the *STEL* in 2000 and the positive improvements made in the following two revisions. Ezra and Bezalel both noted how the smartphone wholly changed society. Simon said that very few teachers were prepared for a worldwide pandemic. Tubal Cain stated, “There's a lot of adaptation that has to be made.” Miriam added, “We're preparing students for jobs that aren't even out there yet.” Technology and engineers noted the need to prepare students to be versatile and adaptable for a future unknown.

Research Question Responses

This section answers this study’s central research question and two sub-questions. Answers are derived from participant perceptions. Quotes from individual interviews and journal prompts provide the rationale.

Central Research Question

What are the experiences of Virginia Technology and Engineering Teachers using integrative STEM methodology to implement the *Standards for Technological and Engineering Literacy* and foster 21st-century learning?

Virginia technology and engineering teachers are innovators. They constantly try to improve their craft, best articulated by Gaspar’s quote, “But again, this is still an ongoing process. After 28 years, I still don't get it right every time. You know, I change stuff every year.” Oholiab noted that technology “goes out of date. Math, English, and history don’t change. It is the same content, year after year. I am constantly relearning technology." Technology and engineering teachers are experiential learners who have been innovators of their craft; the evolution from manual arts to industrial arts, technology education, integrative STEM education, and multiple revisions of the *STEL* created a solid foundation for 21st-century learning.

A design brief describes a problem to be solved with specific requirements and limitations. Teachers responded with limitations and discrepancies between technology and engineering programs in Commonwealth of Virginia schools. Fostering 21st-century learning can be compared to one overarching educational design brief: produce creative problem-solvers with limited resources at your school. Luke replied that integrative STEM methodology "forces creativity to happen" by both students and teachers. Ruth repeated that 21st-century learning comes from "using your resources" and "solving problems." This study demonstrated that integrative STEM methodology and the eight practices of the *STEL* could be used to foster 21st-century learning with a myriad of tools, resources, and supplies.

Sub-Question One

What are the experiences of Virginia Technology and Engineering Teachers with assessing the *Standards for Technical and Engineering Literacy* resulting from integrative STEM instruction?

This study uncovered the difference between measuring and assessing learning in technology and engineering classrooms. This study revealed that the teachers interviewed are more measurers rather than assessors. Teachers in this study primarily used rubrics and self-assessment to generate letter/number grades for report cards. Most teachers in this study responded that machine safety is their only test assessment. Teachers identified learning as a never-ending cycle; growth and improvement are always possible. Ezra presented his dilemma between traditional assessment versus measuring the competency of technological and engineering literacy, “The competency records are assessed on a 5-point scale: 1 (can teach others), 2 (can perform without supervision), 3 (can perform with limited supervision), 4 (can perform with supervision), 5 (cannot perform).” Ezra interpreted a letter grade A to represent “meeting all expectations of an assignment,” however an A letter grade equates to a 2 rating on a competency record. To earn a rating of 1 on a competency record, a student must show they can go above and beyond minimum requirements. Gaspar best explains how technology and engineering teachers assess higher-order thinking, “Creativity is proportionate to time and effort. Creativity is produced when learners go beyond the minimum that is asked of them.” These responses show that the traditional assessment system is not geared toward consistently fostering creativity.

Sub-Question Two

How do Virginia Technology and Engineering teachers using integrative STEM methodology develop a 21st-century curriculum based on experiential learning theory and the *Standards for Technical and Engineering Literacy* frameworks?

Technology and engineering teachers develop a 21st-century curriculum based on two primary experiences: fun and love. Nathanael said, “If you're not having fun, you're not learning. One of my favorite sayings, which I always put on my whiteboard, is “Do what you love, love what you do.” Huldah responded that the 21st-century curriculum is vastly different from the modular labs she facilitated at the beginning of her career. Huldah implied no fun or love with modular labs, stating, “I quickly went back to the interaction within the classroom and made those bonds with the students. I have students who reenroll in my class for 2, 3, or 4 years.” Technology and engineering classes are electives. Students enroll and reenroll because they are having fun with someone who loves their job. Making learning fun and developing quality relationships fosters 21st-century learning.

Summary

The findings in this chapter indicated that technology and engineering teachers perceived that teaching the eight practices of the *STEL* using integrative STEM methodology was the foundation of 21st-century learning and establishing technological and engineering literate students. Measuring and assessing 21st-century learning is an iterative process, using feedback to guide consistent growth in learning. Teachers noted that 21st-century curriculum development should be centered around making learning fun while being empathic in problem-solving.

CHAPTER FIVE: CONCLUSION

Overview

The purpose of this hermeneutic phenomenological study was to understand the perceptions of Virginia Technology and Engineering Teachers using integrative STEM methodology to implement the *STEL* to foster 21st-century learning. This chapter contains a summary of the thematic findings. This chapter also discusses the interpretation of findings, implications for policy and practice, theoretical and methodological implications, limitations and delimitations, and recommendations for future research.

Discussion

This section continues the discussion of data analysis presented in chapter four, beginning with a summary of themes, followed by my interpretation of the findings and the implications for policy or practice. I expound on the theoretical and empirical implications and the study's limitations and delimitations. I conclude with my recommendations for future research in 21st-century learning.

Interpretation of Findings

This section examines the themes presented in Chapter Four. This section begins with a summary of themes, my interpretation of the findings, and the policy and practice implications. I discuss the theoretical and empirical implications of the findings. This section is concluded with the study's limitations and delimitations, along with my recommendations for future research regarding 21st-century learning.

Summary of Thematic Findings

The primary themes identified in this study included the practices of technology and engineering educators, measuring 21st-century learning, and developing 21st-century curriculum. The participants had rich perspectives on 21st-century technology and engineering education, and their professional experiences rendered cogent themes and interpretations. Explanations of the interpretations of participant experiences are in this section.

Integrative Pedagogical Content Knowledge. Purposeful instruction: eight practices of the *STEL* represent the signature PCK of technology and engineering teachers. The teachers in this study overwhelmingly agreed that the eight *STEL* practices should be incorporated into every discipline. Learning to solve problems should be present in more than just technology and engineering classrooms. Technology and engineering teachers naturally and purposefully integrate multiple disciplines and the eight practices of the *STEL* into instruction to foster higher-order thinking. The teachers in this study desire to create an integrative PCK among colleagues of other disciplines to improve 21st-century learning in every classroom.

Teachers confidently noted that grade-level multidisciplinary group projects were the most successful means of 21st-century learning. Teachers explained that multidisciplinary group projects assign one overarching design brief to multiple classes. The multidisciplinary design brief allows colleagues from different disciplines to model collaboration and communication to their students by clearly identifying the real-world problem to be solved and showing the importance that each discipline plays in the problem-solving process. Every class in the design brief breaks off into smaller groups to best solve the problem using the eight practices of the *STEL*. By doing so, students see firsthand that all classes are equally essential and connect learning between disciplines.

The top two tiers of Bloom's hierarchy of learning (1956; Anderson et al., 2001), evaluate and create, are achieved by purposeful incorporation of the eight practices of the *STEL* using design-based group projects. Design-based group projects require communication and collaboration; making group decisions is a higher-order skill (evaluation). Systems thinking requires students to evaluate the input-processes-output-feedback model of innovation by deciding, justifying, prioritizing, and rating feedback. Teaching attention to ethics requires students to evaluate and prioritize just decisions. Teaching optimism requires students to be decisive and prioritize a positive, determined demeanor. Making and doing, critical thinking, and creativity are the highest-order thinking and require students to imagine, plan, design, and create.

The Standards of Learning Examinations from the Virginia Department of Education (VDOE, 2015) only contain test questions that assess the first four levels of Bloom's taxonomy: remember, understand, apply, and analyze. Design-based group projects allow educators to measure and assess all six levels of hierarchal thinking. Design-based group projects also provide a method to implement content; all disciplines have problems to solve.

Cross-curricular collaboration has the potential to innovate and refine learning. Technology and engineering educators cannot only share their defining PCK but can also learn quality PCK from other disciplines that can be incorporated into the innovation of 21st-century learning.

Measuring vs. Assessing Learning. Traditional education uses numerous tests to assess students' knowledge (Sornson, 2023; Stack & Vander Els, 2018). Competency-based learning started in 1968 as a teacher training program to measure how future educators could implement theory (Ford, 2014). Stack and Vander Els (2018) define competency-based education that supports and promotes the need for integrative STEM education, "In a system of competency-based learning, a student's ability to transfer knowledge and apply skills across content areas organizes his or her learning. Transfer means that students are able to take what they have learned (the skills and content within a course) and apply this skill and knowledge across other disciplines to solve unfamiliar problems." (p. 7) Traditional education only assesses, and competency-based education measures and assesses higher-order learning. The teachers in this study faced the challenge of expectations to measure competency and traditionally assess student learning in their classrooms and the hurdles they faced with administrative guidelines.

Tubal Cain explained that using the traditional 4.0 grading scale has produced students with "GPA paralysis." GPA paralysis is when a student is more concerned about the numerical/alphabetical grade received than what skills, knowledge, and experiences gained while enrolled in a course. To fully master the engineering design process, one must learn that some designs will fail. The overwhelming sense of impending failure severely limits innovation for students with high GPAs. GPA paralysis causes students to focus on meeting minimum requirements in every category of an assessment rubric instead of genuinely understanding and mastering the skills, knowledge, and processes introduced in the project.

Students may advance in traditional academia if they are adept at memorizing and following directions. Still, it does not mean all students with an A understand or have mastered the subject matter. Competency-based assessment aims to create an environment where each student receives differentiated support and provides evidence of content mastery and student growth. Technology and engineering classes provide an optimal curricular plan for 21st-century learning.

Integrative STEM methodology allows students to transfer knowledge gained from one discipline to another. Design-based group projects require higher-order thinking and learning the eight practices of the *STEL*. Technology and engineering education competencies aim to produce students capable of teaching others. Workplace Readiness education provides a curriculum framework for students to learn skills, processes, and habits that allow for knowledge to be applied in real-world situations. Technology and engineering education could both measure and assess 21st-century learning.

Experiential Learning. During this study, no teacher used "experiential learning theory" in their dialogue during individual interviews or journal prompts. However, their responses provided an outstanding example of experiential learning in the 21st century. Many teachers responded the easiest thing about being a 21st-century educator was the quality, fulfilling relationships with students. Numerous teachers identified the relationships with students as their main inspiration; many teachers documented the student success stories they encountered in their classes. Relationships are vital to learning. More importantly, relationships are essential to competency.

Optimal competency results from the capacity to teach others, meaning optimal competency requires a group of learners. Being able to teach others requires one to be an experiential learner. Competency and student success stories are produced by integrating the following learning theories that comprise Kolb's experiential learning theory (1984). Vygotsky (1978) established the sociocultural learning theory, meaning you learn from others. Learning from others in technology and engineering classes means one must be able to learn by doing (Dewey, 1915; 1916). Participating in design-based group projects requires three additional learning theories. Follet's management theory (1918) establishes that you must be able to work with others and delegate tasks. Lewin's change theory (1936) proposes that groups are influenced by obstacles, i.e., problems to be solved. Roger's humanistic approach (1959) explains all experiences produce a reaction. While the only learning theory discussed in individual interviews was John Dewey's learning by doing theory (1915; 1916), Kolb's experiential learning theory (1984) provides the criteria needed to obtain competency and student success.

Implications for Policy and Practice

This section contains implications of policy and practice derived from the interpretations of the findings based on the teachers' experiences with 21st-century education. Recommendations for policy include mandating the integration of workplace readiness skills training in every class, requiring technological and engineering literacy in teacher training programs, and establishing universal definitions of "technology," "STEM," and "creativity." Recommendations for practice include integrating the eight practices of the *STEL* into all disciplines, reducing monodisciplinary instruction, and creating more professional development opportunities.

Implications for Policy

The American Educational System is complex. The feedback presented in this study requires alteration of the input to optimize the output. The input in this systems model represents how teachers are trained. Based on participant responses, three fundamental policy changes have the potential to benefit 21st-century education: mandating the integration of workplace readiness skills in all classes, requiring technological and engineering literacy in teacher training programs, and establishing universal definitions of "technology," "STEM," and "creativity."

The Virginia Workplace Readiness Skills (WRS) are 22 standards focus on teaching personal qualities and abilities, interpersonal skills, and professional competency (VDOE, 2022). Every teacher in this study stressed the importance and value of the WRS. While the list of standards was compiled using feedback from employers, teaching WRS teaches skills needed for success in any postsecondary endeavor. Implementing a policy mandating WRS in every class would emphasize the importance of teaching skills such as creativity, conflict resolution, and work ethic.

One of the questions asked in the individual interview portion of data collection was how teachers taught content they were not experts in. Teachers responded that there is natural hesitation in teaching new content and ideas. One strategy would be to train pre-service teachers to be technologically and engineering literate. The eight practices of the *STEL* provide an established curricular framework for higher-order thinking and the capacity to problem-solve. The highest competency assessment in technology and engineering is “capacity to teach others”; if more teachers gain technological and engineering literacy, they gain the confidence to provide a literacy-rich learning environment in their classrooms.

Collectively, teachers in this study clearly defined “technology” as “a diverse collection of processes and knowledge that people use to extend human abilities and satisfy human needs and wants” (Duggar, 2000; ITEEA, 2020). Teachers also noted the term's ambiguity and that “technology” is defined in several ways (Reed, 2018). Teachers offered several definitions of the acronym STEM and a plethora of definitions of the word “creativity.” Teachers could define “technology” because a uniform, standard definition had been established by a governing body (ITEEA) and purposefully taught in teacher training programs. It would be a wise decision for educational governing bodies, preferably at the national level, to eliminate ambiguity and agree upon uniform, standard definitions of 21st-century buzzwords such as technology, STEM, and creativity.

Implications for Practice

Participant responses revealed an exemplary way of facilitating 21st-century learning by purposeful instruction of the eight practices of the *STEL*. Participants showed that 21st-century learning is hands-on, collaborative, integrative, and produces experiential learners. While traditional education still possesses numerous benefits, reducing monodisciplinary instruction and purposefully teaching technological and engineering literacy using multidisciplinary and integrative STEM methodology may be beneficial. The *STEM* (ITEEA, 2020) provides an established list of standards and curricular framework to assist all disciplines in fostering higher-order thinking and preparing students for life in the 21st century.

Several participants noted the importance of professional development within technology and engineering education, whether at a state or national conference or simply brainstorming with colleagues from other schools. Participants detailed the challenges of attending technology and engineering conferences, such as receiving administrative approval to attend a conference, and funding to attend a national conference is often limited. Participants also noted frustration with restrictions about professional development during teacher workdays. Specifically, teachers identified the common practice of system-wide professional development requiring all teachers in the district to learn about one topic. The participants in this study provided a wealth of knowledge; it may also be effective if technology and engineering teachers develop and conduct their professional development training. By doing so, teachers could address two issues facing technology and engineering educators: collaboration with other disciplines and providing identity and relevance to the discipline (Moye et al., 2020). By demonstrating competency in their field by teaching others the importance of technological and engineering literacy, teachers can collaborate and learn from experts in other disciplines.

Theoretical and Empirical Implications

This section addresses the theoretical and empirical implications of this hermeneutical phenomenological study. The theoretical implications show how learning theory for technology and engineering education has evolved and utilizes an innovative learning theory in experiential learning theory. The empirical implications of this study are based mainly on the researcher's experience as a technology and engineering educator. Further explanation is listed below.

Theoretical Implications

The theoretical framework of this study is experiential learning theory (ELT) (Kolb, 1984). For a century, the primary theoretical framework associated with manual arts, industrial arts, technology education, and integrative STEM education was Dewey's learning by doing theory (1915; 1916) presented in Bonser and Mossman's *Industrial Arts for Elementary Schools* (1923). Leonard (2002) explains five primary educational learning theories taught in teacher training programs: behaviorism, cognitive, constructivism, humanism, and connectivism. Experiential learning theory is an integrative theory and does not discredit established learning theories but instead combines them to innovate learning. As manual arts continually innovated to create integrative STEM education, the primary learning theory associated with technology and engineering research also has. Foster (1994) states that "experiential learning has been well established in industrial arts for at least a century" while citing the works of Dewey (1915;1916) as the theoretical framework for the discipline. Theoretical innovation to ELT occurred when Wells (2016) cites Kolb (1984) in his "PIRPOSAL Model of Integrative STEM Education: Conceptual and Pedagogical Framework for Classroom Implementation." Wells' (2016) conceptual framework theorizes that ELT can be enhanced by collaboration and group learning. Yip (2020) conducted ELT research by conducting a study about pre-service teacher training using ELT and integrative STEM methodology at the University of Hong Kong. My study contributed to ELT research by examining teacher understandings to show a connection between workplace readiness skills and collaboration with ELT. The participants' experiences with 21stcentury learning diverged from recent research that asserts ELT is only associated with isolated learning experiences (Ryder & Downs, 2022). This study extended the research by examining how in-service technology and engineering educators utilize ELT in group project instruction.

Empirical Implications

The empirical implications of this study are derived from participants' experience. The participants articulated their belief that integrative STEM methodology and purposeful inclusion of the eight practices of the *STEL* fosters 21st-century learning and yields technological and engineering literate learners. Their beliefs were based on classroom experience and lacked verifiable data. There is no standardized, verified method to measure technological and engineering literacy. Some participants responded their school district(s) required competency-based course grading, meaning a student's course grade reflected their course competency. However, course assessments and course competency records do not have interrater reliability because the teacher is the sole observer of progress. This study sheds light on the current issues and trends facing technology and engineering education (Moye et al., 2020; Moye & Reed, 2020). This study shows that in-service teachers have accepted and implemented the eight practices of the *STEL* in their classrooms, as well as noting the benefit of collaborating with teachers of other content areas. This study also extends the research done by Havice et al. (2018) examining the effectiveness of Grades K-8 integrative STEM education by including Grades 9-12 educators. Overall, the participant responses indicated a progressive evolution of technology and engineering education.

Limitations and Delimitations

The limitations of this study included the participant sample, the geographic location of school sites, and the assumption all teachers used integrative STEM methodology and the eight practices of the *STEL* in their instruction. The delimitations of this study were the site chosen, the credentials of the participants selected, and my reasoning for selecting hermeneutic phenomenology. Further explanations of the limitations and delimitations are listed below.

Limitations

Attempts were made to invite every Virginia Technology and Engineering Educator Association member to participate in this study. The small sample size of fifteen teachers is a limitation. The low response rate of fifteen teachers out of roughly 800 possible participants could be attributed to recruitment invitations sent at the end of the academic school year. The geographic locations of multiple school sites were a limiting factor because geographic location affects school size. Virginia Public Schools are grouped into six divisions dependent on school population. Teachers from five of the six divisions participated in this study. There was no incentive to participate. The participant sample included four women, eleven men, and nine teachers with advanced degrees. The average teaching experience of the participant sample is 15.4 years.

Delimitations

I decided to conduct individual interviews via Zoom for two reasons: the interviews were conducted in June, July, and August, and many teachers would not have complete access to their classrooms, and accessibility to participants in multiple geographical areas. I decided only to use teachers who were certified in technology education who were currently teaching in Grades 6-12. I decided on hermeneutic phenomenology because I was unable to bracket my personal experiences of teaching technology and engineering education out of any portion of this study, and that my experiences and perspective would only enhance this study.

Recommendations for Future Research

Considering the study findings, limitations, and delimitations placed on this study, my recommendations for future research are as follows. This study was conducted in the Commonwealth of Virginia with certified technology and engineering teachers. Future studies could mirror this study's procedures and data collection to expand research into other states, regions, or countries to confirm the transferability of the findings. Several participants identified the TSM Integration Project (LaPorte & Sanders, 1993) as a foundational work for STEM instruction. Considering the confidence in participants responses regarding multidisciplinary instruction, future research could focus on creating a guide of replicable activities that groups of teachers can use to enhance higher-level thinking and promote technological and engineering literacy. Additionally, research regarding the implantation of Workplace Readiness Skills in other content areas could also be beneficial.

Conclusion

This hermeneutical phenomenological study examined 21st-century learning in Virginia technology and engineering classrooms. The theoretical framework for this study is Kolb's (1984) experiential learning theory. Kolb's theory is an innovative combination of nine learning theories that provide a foundation of how 21st-century learning occurs. This study defined 21st-century learning as the eight practices of the *STEL*: communication, collaboration, critical thinking, making and doing, attention to ethics, creativity, systems thinking, and optimism (ITEEA, 2020). Technology and engineering educators were chosen for this study because most disciplines that comprise compulsory education still use antiquated teaching methods and frameworks established in the nineteenth and twentieth centuries. This study consisted of fifteen certified technology and engineering educators (11 male, 4 female) from various schools in the

Commonwealth of Virginia. The fifteen educators had 245.5 combined years of experience teaching technology and engineering education. Each participant completed an individual interview, submitted journal prompts, and provided physical artifacts used in fostering and assessing 21st-century learning. Data were collected, transcribed, and uploaded into Delve data analysis software to be coded. The study produced three main themes: (1) the practices of technology and engineering educators, (2) measuring 21st-century learning, and (3) developing a 21st-century curriculum.

All fifteen participants utilized integrative STEM methodology and the eight practices of the *STEL* in their classrooms. However, several teachers noted that integrative STEM methodology was used as the best method available because of numerous barriers to multidisciplinary instruction. All participants unanimously agreed that 21st-century learning fostered higher-order thinking as defined by Bloom's (1956) learning hierarchy. Several teachers noted the discrepancies between assessing traditional compulsory education versus measuring 21st-century learning, explaining the contradictory methods of learner feedback that traditional grades and competency records provide. This study also identified the ambiguity of the terms: technology, STEM, and creativity. This study ascertained the need for 21st-century multidisciplinary curriculum development, establishing technological and engineering literacy training in teacher training programs, and incorporating workplace readiness skills into all academic disciplines.

References

Act, Every Student Succeeds (2015). Every student succeeds act (ESSA). *Pub. L*, 114-95. congress.gov/114/plaws/publ95/PLAW-114publ95.pdf

Allina, B. (2018). The development of STEAM educational policy to promote student creativity and social empowerment. *Arts Education Policy Review, 119*(2), 77–87. https://doi.org/10.1080/10632913.2017.1296392

American Association of School Librarians. [AASL] (2009). *Standards for the 21st-century learner in action*. American Association of School Librarians.

American Council for Teachers of Foreign Languages [ACTFL]. (2022). *About ACTFL*. ACTFL. https://www.actfl.org/resources/about-actfl

American Federation of Teachers [AFT]. (2022, September 8). *Mission*. American Federation of Teachers. https://www.aft.org/about/mission

American Heritage Dictionary of the English Language (2022). Technology. In *American Heritage Dictionary of the English Language, 5th edition*. https://ahdictionary.com/word/search.html?q=technology&submit.x=39&submit.y=18

American School Counselor Association [ACSA]. (2022). *About ASCA*. Vision, Mission & Goals - American School Counselor Association [ASCA]. https://www.schoolcounselor.org/About-ASCA/Vision,-Mission-Goals

Anderson, L. W., Krathwohl, D. R., & Bloom, B. S. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives* (Abridged ed.). Longman.

Anisimova, T. I., Shatunova, O. V., Sabirova, F. M., & Kazan Federal University, Yelabuga Institute. (2018). STEAM-education as an innovative technology for industry

4.0. *Nauchnyy Dialog, 1*(11), 322-332. https://doi.org/10.24224/2227-1295-2018-11-322-332

Aripin, M. A., Hamzah, R., Setya, P., Hisham, M. H. M., & Ishar, M. I. (2020). Unveiling a new taxonomy in education field. *International Journal of Evaluation and Research in Education*, *9*(3), 524-530.

Aristotle, Ross, W. D., & Brown, L. (2009). *The Nicomachean ethics*. Oxford University Press.

Association for the Advancement of Computing in Education [AACE]. (2022, August 25). *About AACE*. AACE. from https://www.aace.org/about/

Association for Educational Communications in Technology [AECT]. (2022). *About Us*. ABOUT US - Association for Educational Communications and Technology. https://www.aect.org/about_us.php

Association of Supervision and Curriculum Development [ASCD]. (2022). *About Us*. ASCD. https://www.ascd.org/about

Becker, T. (2019). *The four industrial revolutions: Demystifying technological innovation*. (n.p.): Tobias Becker.

Berry, A., Buntting, C., Corrigan, D., Gunstone, R. F., & Jones, A. (2021). *Education in the 21st century: STEM, creativity, and critical thinking*. Springer.

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the quality of learning: The SOLO taxonomy (structure of the observed learning outcome)*. Academic Press.

Blamires, M., & Peterson, A. (2014). Can creativity be assessed? towards an evidence-informed framework for assessing and planning progress in creativity. *Cambridge Journal of Education, 44*(2), 147-162. https://doi.org/10.1080/0305764X.2013.860081

Bloom, B. S. (1956). Taxonomy of educational objectives. Vol. 1: Cognitive domain. *New York: McKay*, *20*(24), 1.

Bolden, B., DeLuca, C., Kukkonen, T., Roy, S., & Wearing, J. (2020). Assessment of creativity in K-12 education: A scoping review. *Review of Education (Oxford), 8*(2), 343-376. https://doi.org/10.1002/rev3.3188

Bonser, F. G., & Mossman, L. C. (1923). *Industrial arts for elementary schools*. Macmillan.

Brusic, S. A., & LaPorte, J. E. (2000). The status of modular technology education in Virginia. *Journal of Industrial Teacher Education*, *38*(1), 5–28.

Buchanan, R. (2019). Systems thinking and design thinking: The search for principles in the world we are making. *She Ji: The Journal of Design, Economics, and Innovation*, *5*(2), 85-104.

Burgason, K. A., Sefiha, O., & Briggs, L. (2019). Cheating is in the eye of the beholder: An evolving understanding of academic misconduct. *Innovative Higher Education*, *44*(3), 203-218.

Cannon, W. B. (1927). The James-Lange theory of emotions: A critical examination and an alternative theory. *The American Journal of Psychology*, *39*(1/4), 106-124.

Care, E., Griffin, P., Scoular, C., Awwal, N., & Zoanetti, N. (2015). Collaborative problem solving tasks. In *Assessment and teaching of 21st century skills* (pp. 85-104). Springer, Dordrecht.

Carnevale, A. P., Fasules, M. L., & Campbell, K. P. (2020). *Workplace basics: The competencies employers want.* Georgetown University Center on Education in the Workforce. https://1gyhoq479ufd3yna29x7ubjn-wpengine.netdna-ssl.com/wp-content/uploads/cew-workplace-basics-fr.pdf

Chai, C. S., Jong, M., Yin, H., Chen, M., & Zhou, W. (2019). Validating and modeling teachers' technological pedagogical content knowledge for integrative science, technology, engineering, and mathematics education. *Educational Technology & Society, 22*(3), 61-73.

Chou, J. (2021). A TRIZ-based product-service design approach for developing innovative products. *Computers & Industrial Engineering,* 161, 107608. https://doi.org/10.1016/j.cie.2021.107608

Chu, H., Martin, S. N., & Park, J. (2018;2019;). A theoretical framework for developing an intercultural STEAM program for Australian and Korean students to enhance science teaching and learning. *International Journal of Science and Mathematics Education, 17*(7), 1251-1266. https://doi.org/10.1007/s10763-018-9922-y

Clark, S. C. (1989). The industrial arts paradigm: adjustment, replacement, or extinction? *Journal of Technology Education*, *1*(1). https://doi.org/10.21061/jte.v1i1.a.3

Code, J., Ralph, R., & Forde, K. (2020). Pandemic designs for the future: perspectives of technology education teachers during COVID-19. *Information and Learning Sciences*.

Cohen, D., & Crabtree, B. (2006). Qualitative research guidelines project. https://sswm.info/sites/default/files/reference_attachments/COHEN%202006%20Semistructured%20Interview.pdf.

Colton, S., Smith, C. E., & Sourdot, L. A. (2020). Designing a future classroom laboratory for exploring the science of teaching and learning. *International Journal of Designs for Learning, 11*(3), 36-46. https://doi.org/10.14434/ijdl.v11i3.25860

Common Core State Standards [CCSS]. (2022). *Home | common core state standards initiative*. CCSS. http://www.corestandards.org/

Conradty, C., & Bogner, F. X. (2020). STEAM teaching professional development works: Effects on students' creativity and motivation. *Smart Learning Environments, 7*(1), 1-20. https://doi.org/10.1186/s40561-020-00132-9

Council for Exceptional Children [CEC]. (2022). *About Us*. Council for Exceptional Children. https://exceptionalchildren.org/about-us

Council, N. R., Education, Division of Behavioral and Social Sciences and, Education, B. o. S., Standards, Committee on a Conceptual Framework for New K-12 Science Education, Keller, T., Quinn, H., Schweingruber, H., National Research Council (U.S.). Committee on a Conceptual Framework for New K-12 Science Education Standards, Committee on a Conceptual Framework for New K-12 Science Education Standards, Division of Behavioral and Social Sciences and Education, National Research Council, & Board on Science Education. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. https://doi.org/10.17226/13165

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry & research design: Choosing among five approaches* (Fourth ed.). SAGE.

Curtis Dolby, J. H., & Brazil, N. (2010). *Billy biscuit: the colourful life and times of Sir William Curtis, 1752-1829*. Brazil Productions.

Daugherty, M. K. (2013). The prospect of an "A" in STEM education. *Journal of STEM Education: Innovations and Research, 14*(2), 10–15. http://ojs.jstem.org/index.php/JSTEM/article/view/1744/1520

Dede, C. (2010). Comparing frameworks for 21st century skills. *21st century skills: Rethinking how students learn*, *20*(2010), 51-76.

De la Garza, A., & Travis, C. (2019;2018;). *The STEAM revolution: Transdisciplinary approaches to science, technology, engineering, arts, humanities, and mathematics*. Springer.

Department of Education (ED). (2010). *Report to the white house council on women and girls. U.S. Department of Education Agency report*. Distributed by ERIC Clearinghouse. https://eric.ed.gov/?id=ED517201.

DeSilver, D. (2020, August 21). *U.S. academic achievement lags that of many other countries*. Pew Research Center. https://www.pewresearch.org/fact-tank/2017/02/15/u-s-students-internationally-math-science/

Dewey, J., & Dewey, E. (1915). *Schools of tomorrow.* E. P. Dutton & Company.

Dewey, J. (1916). *Democracy and education.* The Macmillan Company.

Dubek, M., DeLuca, C., & Rickey, N. (2021). Unlocking the potential of STEAM education: How exemplary teachers navigate assessment challenges. *The Journal of Educational Research (Washington, D.C.), 114*(6), 513-525. https://doi.org/10.1080/00220671.2021.1990002

Dugger Jr, W. E. (2000). Standards for technological literacy. Content for the study of technology. *Technology Teacher*, *59*(5), 8-13.

Dugger Jr, W. E. (2013, October). The progression of technology education in the USA. In *Pacific Rim International Conference on Technology Education, Technology Education Institute of Nanjing Normal University.* https://www.iteea.org/File.aspx?id=47099&v=662e0da9

Dye, C. M. (1974). Woodward and manual training: Early reform in American secondary schools. *American Secondary Education*, *4*(*3*), *20-22*.

Eckhoff, A. (2020). *Provoking curiosity: Student-led STEAM learning for pre-K to third grade*. Gryphon House.

Ekiz-Kiran, B., & Aydin-Gunbatar, S. (2021). Analysis of engineering elements of K-12 science standards in seven countries engaged in STEM education reform. *Science & Education, 30*(4), 849-882. https://doi.org/10.1007/s11191-021-00227-w

Follett, M. P. (1918). *The new state: group organization the solution of popular government*. Longmans, Green.

Follett, M. P. (1924). *Creative experience.* Longmans, Green, and company.

Ford, K. (2014). Competency-based education: History, opportunities, and challenges. *UMUC Center for Innovation in Learning and Student Success*, *10*, 24. https://files.eric.ed.gov/fulltext/ED114384.pdf

Freire, P. (1970). *Pedagogy of the oppressed.* (M. B. Ramos, Trans.) (Ser. A continuum book). Herder and Herder.

Freire, P. (1973). *Education for critical consciousness.* Continuum.

Geesa, R. L., Rose, M. A., & Stith, K. M. (Eds.). (2021). *Leadership in integrative STEM education: Collaborative strategies for facilitating an experiential and student-centered culture*. Rowman & Littlefield.

Giani, M. S. (2019). Who is the modern CTE student? A descriptive portrait of career and technical education students in Texas.

González-Pérez, L. I., & Ramírez-Montoya, M. S. (2022). Components of education 4.0 in 21st century skills frameworks: Systematic review. *Sustainability (Basel, Switzerland), 14*(3), 1493. https://doi.org/10.3390/su14031493

Griffin, P. E., & Care, E. (2014;2015;). *Assessment and teaching of 21st century skills: Methods* *and approach*. Springer. https://doi.org/10.1007/978-94-017-9395-7

Haapaniemi, J., Venäläinen, S., Malin, A., & Palojoki, P. (2019). Home economics education: Exploring integrative learning. *Educational Research (Windsor), 61*(1), 87-104. https://doi.org/10.1080/00131881.2018.1564626

Hall, C. W. (1973). *Black vocational, technical, and industrial arts education; development and history.* American Technical Society.

Han, Kelley, T., Bartholomew, S., & J. (2020). Sharpening STEL with integrated STEM. *Technology & Engineering Teacher.*, *80*(3).

Harris, K. S. (2005). Teachers' perceptions of modular technology education laboratories. *Journal of Industrial Teacher Education*, *42*(4), 52–71.

Harton, H. C., Aladia, S., & Gordon, A. (2019). Faculty and student perceptions of cheating in online vs. traditional classes. *Online Journal of Distance Learning Administration*, *22*(4), 4.

Hastings, S. O., Aponte, S., Valverde, E., Gristock, C., Fraser, R., Missigman, M., ... & Rosas, L. (2020). Nonverbal communication and writing deficiencies of graduates: Research by undergraduates for undergraduates. *Business and Professional Communication Quarterly*, *83*(2), 204-222.

Havice, W., Havice, P., Waugaman, C., & Walker, K. (2018). Evaluating the effectiveness of integrative STEM education: Teacher and administrator professional development. *Journal of Technology Education*, *29*(2), 73-90.

Heilig, J. V., Brewer, T. J., & White, T. (2018). What instead?: Reframing the debate about charter schools, teach for America, and high-stakes testing. *Counterpoints (New York, N.Y.), 523*, 201-217.

Henriksen D., Mehta R., Mehta S. (2019). Design thinking gives STEAM to teaching: A framework that breaks disciplinary boundaries. In: Khine M., Areepattamannil S. (eds) *STEAM Education*. Springer, Cham. https://doi-org.ezproxy.liberty.edu/10.1007/978-3-030-04003-1_4

Henseler, C. (2020). *Extraordinary partnerships: How the arts and humanities are transforming America*. Lever Press. https://doi.org/10.3998/mpub.11649046

Herro, D., Quigley, C., Andrews, J., & Delacruz, G. (2017). Co-measure: Developing an assessment for student collaboration in STEAM activities. *International Journal of STEM Education, 4*(1), 1-12. https://doi.org/10.1186/s40594-017-0094-z

Herro, D., & Quigley, C. (2017). Exploring teachers' perceptions of STEAM teaching through professional development: Implications for teacher educators. *Professional Development in Education, 43*(3), 416-438. https://doi.org/10.1080/19415257.2016.1205507

Hirsch, E. D. (2019). *Why knowledge matters: Rescuing our children from failed educational theories*. Harvard Education Press.

Holowchak, M. A. (2014). Jefferson's platonic republicanism. *Polis, 31*(2), 369-386. https://doi.org/10.1163/20512996-12340021

Holy Bible: *New International Version*. (2011). Bible Hub. https://www.biblehub.com/ (Original work published 1984)

Hullfish, H. G., & Smith, P. G. (1961). *Reflective thinking: The method of education*. Dodd, Mead.

Hutner, T. L., Sampson, V., Chu, L., Baze, C. L., & Crawford, R. H. (2022). A case study of science teachers' goal conflicts arising when integrating engineering into science classes. *Science Education (Salem, Mass.), 106*(1), 88-118. https://doi.org/10.1002/sce.21690

Industrial Commission of Ohio. Division of Safety & Hygiene, & Krise, M. H. (1966). *Industrial arts & vocational education: safety manual.* Div. of Safety and Hygiene.

International Society for Technology in Education [ISTE]. (2022). https://www.iste.org/about/iste-story

International Society for Technology in Education [ISTE]. (2022). *The ISTE standards for digital literacy.* https://www.iste.org/iste-standards

International Technology and Engineering Educators Association. [ITEEA] (2020). *Technological literacy standards*. ITEEA. https://www.iteea.org/51801.aspx.

International Technology and Engineering Educators Association (ITEEA). (2020). *Standards for technological and engineering literacy: the role of technology and engineering in STEM education.* www.iteea.org/STEL.aspx

James, W., Drummond, R., & Henry Holt and Company. (1890). *The principles of psychology* (Ser. American science--advanced course). Henry Holt and Company.

Jang, H. (2016). Identifying 21st century stem competencies using workplace data. *Journal of Science Education and Technology*, *25*(2), 284–301.

Jao, L., & Radakovic, N. (2018;2017;). In Jao L., Radakovic N.(Eds.), *Transdisciplinarity in mathematics education: Blurring disciplinary boundaries*. Springer. https://doi.org/10.1007/978-3-319-63624-5

Jefferson, T., & Looney, J. J. (2016). *The papers of thomas jefferson: 1 September 1817 to 21 April 1818*. Princeton University Press.

Jung, C. G. (1969). *The archetypes and the collective unconscious.* (R. F. C. Hull, Trans.) (Second, Ser. The collected works of C.G. Jung, v.9, pt. 1). Princeton University Press.

Kelley, T. R. (2011). Engineer's notebook--A design assessment tool. *Technology and Engineering Teacher, 70*(7), 30.

Kelley, T. & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11). https://doi.org/10.1186/s40594-016-0046-z

Kelley, T. R., Knowles, J. G., Han, J., & Sung, E. (2019). Creating a 21st century skills survey instrument for high school students. *American Journal of Educational Research*, *7*(8), 583-590.

Kesici, A. E., & Çavuş, B. (2019). The evaluation of teacher training programs in the United States of America in terms of student-centered practices used in class. *Journal of Education and Training Studies, 7*(10), 78. https://doi.org/10.11114/jets.v7i10.4462

Khan, S. (2012). *The one world schoolhouse: Education reimagined*. Twelve.

Khine, M. S., & Areepattamannil, S. (2019). *STEAM education: Theory and practice*. Springer. https://link-springer-com.ezproxy.liberty.edu/book/10.1007%2F978-3-030-04003-1

Kim, K. H. (2019). Demystifying creativity: What creativity isn't and is? *Roeper Review, 41*(2), 119-128. https://doi.org/10.1080/02783193.2019.1585397

Kim, Y., & Park, N. (2012). Development and application of STEAM teaching model based on the Rube Goldberg's invention. In *Computer science and its applications* (pp. 693–698). Springer.

King, H., & King, W. (2017). *The wild card: 7 steps to an educator's creative breakthrough*. Dave Burgess Consulting, Inc.

Kolb, D. A. (1984; 2014). *Experiential learning: Experience as the source of learning and development*. F.T. press.

Koul, R. B., Sheffield, R., & McIlvenny, L. (2021). *Teaching 21st century skills: Using STEM makerspaces*. Springer.

Kupers, E., Lehmann-Wermser, A., McPherson, G., & van Geert, P. (2019). Children's creativity: A theoretical framework and systematic review. *Review of Educational Research, 89*(1), 93-124. https://doi.org/10.3102/0034654318815707

Lajoie, J., Orchard, A., & Love, H. A. (2020, November). Ethical tech pedagogy for public good: A review of educational initiatives and approaches. In *2020 IEEE International Symposium on Technology and Society (ISTAS)* (pp. 29-32). IEEE.

Lane, C., Kaya-Capocci, S., Kelly, R., O'Connell, T., & Goos, M. (2022). Fascinating or dull? female students' attitudes towards STEM subjects and careers. *Frontiers in Psychology, 13*, 959972-959972. https://doi.org/10.3389/fpsyg.2022.959972

LaPorte, J. E., & Sanders, M. E. (1993). TSM integration project: integrating technology, science, and mathematics in the middle school. *The Technology Teacher.* 17-21. http://hdl.handle.net/10919/51623

Lee, D. (2021). The effect of STEAM-based physical education classes on middle school students' attitudes toward physical education classes and self-directed learning abilities. *Iranian Journal of Public Health, 50*(5), 938-948. https://doi.org/10.18502/ijph.v50i5.6111

Lee, Y. (2021). Examining the impact of STEAM education reform on teachers' perceptions about STEAM in Uzbekistan. *Asia-Pacific Science Education, 7*(1), 34-30. https://doi.org/10.1163/23641177-bja10025

Leonard, D. (2002). *Learning theories: A to Z* (1st ed.). ABC-CLIO, LLC.

Levy, F., & Murnane, R. J. (2004). *The new division of labor: How computers are creating the next job market.* Princeton University Press.

Lewin, K. (1936). *Principles of topological psychology*. McGraw-Hill.

Lewin, K. (1939). Field theory and experiment in social psychology: concepts and methods. *American Journal of Sociology*, *44(*6), 868–896.

Liang, Q., Niu, W., Cheng, L., & Qin, K. (2022). Creativity outside school: The influence of family background, perceived parenting, and after-school activity on creativity. *The Journal of Creative Behavior, 56*(1), 138-157. https://doi.org/10.1002/jocb.521

Limna, P., Siripipattanakul, S., & Auttawechasakoon, P. (2022). A qualitative study of ethical change management affecting teacher satisfaction and school performance: A case study of secondary schools in Krabi, Thailand. *International Journal of Trend in Scientific Research and Development (IJTSRD) Vol. 6*.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry.* Sage Publications.

Lord, K. C. (2019). Flexible learning: The design thinking process as a K-12 educational tool. *Journal of Higher Education Theory and Practice, 19*(7), 54-61. https://doi.org/10.33423/jhetp.v19i7.2531

Love, T. S., Duffy, B. C., Loesing, M. L., Roy, K. R., & West, S. S. (2020). Safety in STEM education standards and frameworks: A comparative content analysis. *Technology and Engineering Teacher, 80*(3), 34.

Love, T. S., & Hughes, A. J. (2022). Engineering pedagogical content knowledge: Examining correlations with formal and informal preparation experiences. *International Journal of STEM Education, 9*(1), 1-20. https://doi.org/10.1186/s40594-022-00345-z

Love, T. S. (2022). Examining the influence that professional development has on educators' perceptions of integrated STEM safety in makerspaces. *Journal of Science Education and Technology, 31*(3), 289-302. https://doi.org/10.1007/s10956-022-09955-2

Love, T. S., Roy, K. R., & Sirinides, P. (2023). A national study examining safety factors and training associated with stem education and cte laboratory accidents in the United States. *Safety Science*, *160*. https://doi.org/10.1016/j.ssci.2022.106058

Lucas, C. J. (2016). *American higher education: A history.* Pelgrave Macmillan

Lv, B., Wang, J., Zheng, Y., Peng, X., & Ping, X. (2022). Gender differences in high school students' STEM career expectations: An analysis based on multi-group structural equation model. *Journal of Research in Science Teaching, 59*(10), 1739-1764. https://doi.org/10.1002/tea.21772

Mackenzie, J. C. (1894). The report of the committee of ten. *The school review, 2(3),* 146-155. http://www.jstor.org/stable/1074830

Marshall, C., & Rossman, G. B. (2006). *Designing qualitative research* (4th ed.). Sage Publications.

Martinez, C. (2022). Developing 21st century teaching skills: A case study of teaching and learning through project-based curriculum. *Cogent Education, 9*(1)https://doi.org/10.1080/2331186X.2021.2024936

Martinez, J. E. (2017). *The search for method in STEAM education*. Palgrave Macmillan.

Marzano, R. J., & Kendall, J. S. (Eds.). (2006). *The new taxonomy of educational objectives*. Corwin Press.

Michigan Technological University [MTU]. (2022, October 2). *Engineering salary statistics*. Michigan Technological University. https://www.mtu.edu/engineering/outreach/welcome/salary/

Moye, J. J. (2009). Technology education teacher supply and demand-a critical situation. *Technology and Engineering Teacher*, *69*(2), 30.

Moye, J. J., & Reed, P. A. (2020). Standards for technological and engineering literacy: addressing trends and issues facing technology and engineering education. *Technology & Engineering Teacher*, *80*(3).

Moye, J. J., Reed, P. A., Wu-Rorrer, R., & Lecorchick, D. (2020). Current and future trends and issues facing technology and engineering education in the United States. *Journal of Technology Education*, *32*(1).

Mullen, C. A. (2019;2018;). *Creativity under duress in education?: Resistive theories, practices, and actions*. Springer.

Nadiroh, N., Zulfa, V., & Yuliani, S. (2021). Learning transformation of the 21st century curriculum for prospective teacher in term of eco-literacy. *IOP Conference Series. Earth and Environmental Science, 802*(1), 12009. https://doi.org/10.1088/1755-1315/802/1/012009

Nalipay, M. J. N., Jong, M. S. Y., Chiu, T. K., & Chai, C. S. (2022, July). Teachers' technological pedagogical content knowledge for integrative science, technology, engineering, and mathematics education. In *2022 International Symposium on Educational Technology (ISET)* (pp. 37-41). IEEE.

National Academy of Engineering [NAE]. (2022). *NAE grand challenges of engineering: 14 grand challenges for engineering in the 21st century*. Grand Challenges - 14 grand challenges for engineering. Retrieved February 5, 2022, from http://www.engineeringchallenges.org/challenges.aspx

National Art Educators Association [NAEA]. (2022). *About US* National Art Education Association. https://www.arteducators.org/about

National Assessment of Academic Progress [NAEP]. (2022). *NAEP report cards - home*. The Nation's Report Card. https://www.nationsreportcard.gov/

National Association for Gifted Children [NAGC]. (2022). *Who we are*. Who We Are | National Association for Gifted Children. https://www.nagc.org/about-nagc/who-we-are

National Association for Music Education [NAfME]. (2022, September 13). *Mission and goals*. NAfME. https://nafme.org/about/mission-and-goals/

National Business Education Association [NBEA]. (2022). *About NBEA - National Business Education Association*. About Us. https://nbea.org/page/About

National Commission on Excellence in Education [NCEE]. (1983). A nation at risk: The imperative for educational reform. *The Elementary School Journal, 84(2),* 113-130.

National Council for Agricultural Education [NCAE]. (2022, August 9). *About Us*. The National Council for Agricultural Education. https://thecouncil.ffa.org/about-us/

National Council for the Social Studies [NCSS]. (2022). *About National Council for the Social Studies*. About National Council for Social Studies. https://www.socialstudies.org/about

National Council for the Social Studies [NCSS]. (2022). *NCSS Social Studies Standards*. Social Studies. https://www.socialstudies.org/standards

National Council of Teachers of English [NCTE]. (2022). *About National Council of Teachers of English*. About NCTE. https://ncte.org/about/

National Council for the Teachers of English [NCTE]. (2017, November 29). *Standards*. NCTE. https://ncte.org/resources/standards/

National Council of Teachers of Mathematics [NCTM]. (2022). *About NCTM*. Nctm.org. https://www.nctm.org/About/

National Council for the Teachers of Mathematics [NCTM]. (2018). *Building STEM Education on a Sound Mathematics Foundation* [PDF]. https://www.nctm.org/uploadedFiles/Standards_and_Positions/Position_Statements/Building%20STEM%20Education%20on%20a%20Sound%20Mathematical%20Foundation%20(NCSM-NCTM%202018).pdf

National Council for Teachers of Mathematics [NCTM]. (2022). *Building STEM Education on a Sound Mathematics Foundation*. Nctm.org. https://www.nctm.org/Standards-and-Positions/Position-Statements/Building-STEM-Education-on-a-Sound-Mathematical-Foundation/

National Council for Teachers of Mathematics [NCTM] (2022). *Principles and Standards*. Nctm.org. https://www.nctm.org/Standards-and-Positions/Principles-and-Standards/

National Education Association [NEA]. (2019). *An educator's guide to the "four C's": Preparing 21st-century students for a global society*. NEA. https://www.nea.org/professional-excellence/student-engagement/tools-tips/being-21st-century-educator

National Education Association [NEA]. (2022). *About NEA*. NEA. https://www.nea.org/about-nea

National Parent Teacher Association [NPTA]. (2022). *Mission statement & values - about PTA: National PTA*. National Parent Teacher Association. https://www.pta.org/home/About-National-Parent-Teacher-Association/Mission-Values

National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. National Academies Press.

National Research Council. (1996). *National science education standards*. National Academies Press.

National Science Teacher Association [NSTA]. (2022). *National Science Teacher Association Overview*. NSTA. https://www.nsta.org/overview

National Science Teacher Association [NSTA]. (2022). *Science standards*. NSTA. https://www.nsta.org/science-standards

National Science Teacher Association [NSTA]. (2022). *NTSA Strategic Plan*. NSTA. https://static.nsta.org/pdfs/NSTAStrategicPlan22_infographic.pdf

Nelson, L. (1980). The Socratic method. *Thinking: The Journal of Philosophy for Children*, *2*(2), 34-38.

Nishitha, P., & Pandey, D. (2021). A study on student perception towards online education during covid-19 crisis. *Augmented Human Research*, *6*(1), 1-7.

No Child Left Behind (NCLB). (2002). No child left behind act. *Washington, DC: US Department of Education*.

North Central Regional Educational Laboratory (NCREL). (2003). *enGauge 21st centurysSkills*. 21st Century skills. Retrieved November 30, 2022, from https://www.ncrel.org/engauge/skills/skills.html

Oleson, A., & Hora, M. T. (2014). Teaching the way they were taught? Revisiting the sources of teaching knowledge and the role of prior experience in shaping faculty teaching practices. *Higher Education, 68(1),* 29-45. https://doi.org/10.1007/s10734-013-9678-9

Organization for Economic Co-operation and Development (OECD). (2005). *The definition and selection of key competencies: Executive summary*. Paris: OECD.

Ostroff, W. L. (2016). *Cultivating curiosity in K-12 classrooms: How to promote and sustain deep learning*. ASCD.

Ozkan, G., & Umdu Topsakal, U. (2019;2021;). Exploring the effectiveness of STEAM design processes on middle school students' creativity. *International Journal of Technology and Design Education, 31*(1), 95-116. https://doi.org/10.1007/s10798-019-09547-z

Ozkan, G., & Umdu Topsakal, U. (2021). Investigating the effectiveness of STEAM education on students' conceptual understanding of force and energy topics. *Research in Science & Technological Education, 39*(4), 441-460. https://doi.org/10.1080/02635143.2020.1769586

Paolucci, C., & Stepp, Z. A. (2021). Examining preservice teachers' understanding of slope through posing problems and embedding learning in real-world contexts. *Teaching and Teacher Education, 107*, 103476. https://doi.org/10.1016/j.tate.2021.103476

Park, Y. (2021). The perception of special education teachers' perception of implementing STEAM education for students with intellectual disabilities. *Turkish Journal of Computer and Mathematics Education, 12*(10), 925-932.

Partnership for 21st Century Skills [P21]. (2009). P21 framework definitions. https://files.eric.ed.gov/fulltext/ED519462.pdf

Partnership for 21st Century Learning [P21]. (2022). *Framework for 21st Century learning definitions - battelle for kids*. Frameworks & Resources. https://static.battelleforkids.org/documents/p21/P21_Framework_DefinitionsBFK.pdf

Patton, M. Q. (2015). *Qualitative research & evaluation methods: Integrating theory and practice* (Fourth ed.). SAGE Publications, Inc.

Piaget, J. (1929). *Introduction to the child's conception of the world*. Harcourt.

Piaget, J. (1953). *The origin of intelligence in the child* (Ser. International library of psychology, philosophy, and scientific method). Routledge & Kegan Paul.

Plato, Fowler, H. N., Lamb, W. R. M. Sir, Bury, R. G., & Shorey, P. (1964). *Plato: The Republic*. Harvard University Press. (Original work published ca. 375 B.C.E.)

Pouspourika, K. (2020, May 4). *The 4 industrial revolutions.* Institute of entrepreneurship development. https://ied.eu/project-updates/the-4-industrial-revolutions/.

Rahmawati, Y., & Taylor, P. C. (2019). *Empowering science and mathematics for global competitiveness: Proceedings of the science and mathematics international conference (SMIC 2018), november 2-4, 2018, Jakarta, Indonesia*. Taylor & Francis Group.

Reed, P. A. (2018). Reflections on STEM, standards, and disciplinary focus*. Technology & Engineering Teacher, 77*(7), 16–20.

Renner, R. (2022). *Christmas - The Rest of the Story.* Harrison House.

Rhodes, M. (1961/1987). An analysis of creativity. In S. G. Isaksen (Ed.), *Frontiers of creativity research* (pp. 216–222). Bearly Limited.

Robinson, K. (2017). *Out of our minds: The power of being creative* (Third ed.). Capstone.

Rogers, C. R. (1959). *A theory of therapy, personality, and interpersonal relationships: as developed in the client-centered framework.* (S. Koch, Ed.). McGraw-Hill.

Rothbard, M. N. (1979). *Education: Free and compulsory*. Ludwig von Mises Institute.

Ryder, M., & Downs, C. (2022). Rethinking reflective practice: John Boyd's OODA loop as an alternative to Kolb. *The International Journal of Management Education*, *20*(3), 100703.

Saldaña, J. (2013). *The coding manual for qualitative researchers* (Second ed.). SAGE.

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher*.

Sanders, M. E. (2013). Integrative STEM education defined. http://hdl.handle.net/10919/51617

Sanders, M. E. (2015). The original "integrative STEM education" definition: Explained.

Sanders, M.E. & Wells, J.G. (2010) Virginia tech, Integrative STEM education graduate Program http://web.archive.org/web/20100924150636/http://www.soe.vt.edu/istemed

Sawstop. (2022, November 22). *America's #1 table saw. the leader in table saw safety*. Sawstop. https://www.sawstop.com/

Sawyer, R. K. (2011). *Explaining creativity: The science of human innovation.* Oxford University Press.

Schwab, K. (2017). *The fourth industrial revolution*. Crown.

Sengupta, P., Shanahan, M., & Kim, B. (2019). *Critical, transdisciplinary, and embodied approaches to STEM education*. Springer.

Şentürk, C. (2020;2021;). Effects of the blended learning model on preservice teachers' academic achievements and twenty-first century skills. *Education and Information Technologies, 26*(1), 35-48. https://doi.org/10.1007/s10639-020-10340-y

Sima, V., Gheorghe, I. G., Subić, J., & Nancu, D. (2020). Influences of the industry 4.0 revolution on the human capital development and consumer behavior: A systematic review. *Sustainability (Basel, Switzerland), 12*(10), 4035. https://doi.org/10.3390/su12104035

Snieder, R., & Zhu, Q. (2020). Connecting to the heart: Teaching value-based professional ethics. *Science and Engineering Ethics*, *26*(4), 2235–2254. https://doi-org.ezproxy.liberty.edu/10.1007/s11948-020-00216-2

Shahroom, A. A., & Hussin, N. (2018). Industrial revolution 4.0 and education. *International Journal of Academic Research in Business and Social Sciences*, *8*(9), 314-319.

Sharratt, L., & Harild, G. (2015). *Good to great to innovate: Recalculating the route to career readiness, K-12*. Corwin, a Sage Company.

Shalevska, E. (2021). Cheating and academic dishonesty and covid-19 distance learning. *International Journal of Education, 21*(18). https://repository.ukim.mk/bitstream/20.500.12188/18985/1/8-3-PB%20%28Ucitel%202021%29.pdf#page=18

Shively, K., Stith, K. M., & Rubenstein, L. D. (2018). Measuring what matters: Assessing creativity, critical thinking, and the design process. *Gifted Child Today Magazine, 41*(3), 149-158. https://doi.org/10.1177/1076217518768361

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (2013). Those who understand: Knowledge growth in teaching. *The Journal of Education*, *193(3), 1–11*. http://www.jstor.org/stable/24636916

Sima, V., Gheorghe, I. G., Subić, J., & Nancu, D. (2020). Influences of the industry 4.0 revolution on the human capital development and consumer behavior: A systematic review. *Sustainability (Basel, Switzerland), 12*(10), 4035. https://doi.org/10.3390/su12104035

Snow, C. P. (1959). *The two cultures and the scientific revolution: The Rede lecture*. Cambridge University Press.

Society of Health and Physical Educators (SHAPE America) (2022). *About shape America.* about SHAPE America- society of health and physical educators. https://www.shapeamerica.org/about/default.aspx

Sornson. (2023). *Over-tested and under-prepared: Shifting from one-size-fits-all instruction to personalized competency based learning* (Second edition.). Routledge, Tayloe & Francis Group

Sousa, D. A. (2016). *Engaging the rewired brain*. Learning Sciences International.

Sousa, D. A. (2017). *How the brain learns*, 5th edition. Corwin.

Sousa, D. A., & Tomlinson, C. A. (2011). *Differentiation and the brain: How neuroscience supports the learner-friendly classroom*. Solution Tree Press.

Sousa, D. A., & Pilecki, T. (2018). *From STEM to STEAM: Brain-compatible strategies and lessons integrating the arts* (2nd ed.). Corwin. https://dx.doi.org/10.4135/9781544357393

Stack, & Vander Els, J. G. (2018). *Breaking with tradition: The shift to competency-based learning in PLCs at WorkTM*. Solution Tree Press.

Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM education*, *6*(1), 1-15.

Stenard, B. S. (2021). Interdisciplinary skills for STEAM entrepreneurship education. *Entrepreneurship Education and Pedagogy,* 251512742110292. https://doi.org/10.1177/25151274211029204

Stevens, F. I. (1993). *User-friendly handbook for project evaluation: Science, mathematics, engineering, and technology education*. National Science Foundation, Directorate for Education and Human Resources. https://eric.ed.gov/?id=ED366511

Stephens, J. T. (2019). Teaching critically where rural and nonrural cultures intersect. *American Educational Research Journal, 56*(6), 2043-2076. https://doi.org/10.3102/0002831219839311

Stewart, A. J., Mueller, M. P., & Tippins, D. J. (2019;2020;). *Converting STEM into STEAM programs: Methods and examples from and for education*. Springer.

Stone, R. B. (1953). *Accidents and their causes in selected industrial arts shops of Iowa.* (Master's thesis, Iowa State College).

Sunarti, T., Wasis, W., Madlazin, M., & Suyidno, S. (2020, March). Multidisciplinary, interdisciplinary, and transdisciplinary approaches in literacy learning model. In *Journal of Physics: Conference Series* (Vol. 1491, No. 1, p. 012054). IOP Publishing.

Teach for America (TFA). (2022). *Home*. Teach For America. https://www.teachforamerica.org/

Teo, T., Unwin, S., Scherer, R., & Gardiner, V. (2021). Initial teacher training for twenty-first century skills in the fourth industrial revolution (IR 4.0): A scoping review. *Computers and Education, 170*, 104223. https://doi.org/10.1016/j.compedu.2021.104223

Trott, C. D., Even, T. L., & Frame, S. M. (2020). Merging the arts and sciences for collaborative sustainability action: A methodological framework. *Sustainability Science, 15*(4), 1067-1085. https://doi.org/10.1007/s11625-020-00798-7

United States Department of Education (U.S. DOE). (2011, October 20). *The mission of U.S. education*. Mission Statement. https://www2.ed.gov/about/overview/mission/mission.html

Valverde, J. d., Thornhill-Miller, B., Patillon, T., & Lubart, T. (2020). Creativity: A key concept in guidance and career counseling. *Journal of Adult and Continuing Education, 26*(1), 61-72. https://doi.org/10.1177/1477971420903736

van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior, 72*, 577-588. https://doi.org/10.1016/j.chb.2017.03.010

Van Manen, M. (1990). *Researching lived experience: human science for an action sensitive pedagogy* (Ser. Suny series in the philosophy of education). State University of New York Press.

Vermesan, O., Friess, P., Guillemin, P., Giaffreda, R., Grindvoll, H., Eisenhauer, M., ... & Tragos, E. Z. (2022). Internet of things beyond the hype: Research, innovation, and deployment. In *Building the hyperconnected societyiInternet of things research and innovation value chains, ecosystems and markets* (pp. 15-118). River Publishers.

Virginia Association of Science Teachers (VAST). (2023). *About VAST*. Virginia Association of Science Teachers - about. https://vast.wildapricot.org/About-VAST

Virginia Association of Teachers of English (VATE). (2023). *About Us.* vate.org. https://vate.org/about-us/

Virginia Children's Engineering Council. (2022). *Engineering Virginia's future.* https://sites.google.com/view/virginia-childrens-engineering/home?pli=1

Virginia Council for Teachers of Mathematics (VCTM). (2023). *Constitution - Virginia Council of Teachers of Mathematics*. Virginia Council of Teachers of Mathematics - Constitution. https://www.vctm.org/constitution/#ArticleII

Virginia Council for the Social Studies (VCSS). (2023). *VCSS*. https://sites.google.com/vcss.org/vacouncilforthesocialstudies//

Virginia CTE Resource Center (VERSO). (2022). *Workplace Readiness Skills.* The CTE Resource Center. https://www.cteresource.org/resources/workplace-readiness-skills/

Virginia Department of Education (VDOE). (2015). *Standards of learning (SOL) Frequently Asked Questions (FAQ)*. VDOE: Standards of Learning (SOL) and Testing. Retrieved November 15, 2022, from https://doe.virginia.gov/testing/sol_faq.pdf

Virginia Department of Education (VDOE). (2017). *Virginia Board of Education Comprehensive Plan: 2018-2023.* https://www.doe.virginia.gov/home/showpublisheddocument/1154/637946384285670000

Virginia Department of Education (VDOE). (2022). *Academic and career plans of study*. VDOE: Career & Technical: Academic and Career Plans of Study. https://www.doe.virginia.gov/instruction/career_technical/career_clusters/plans_of_study/index.shtml

Virginia Department of Education (VDOE). (2022). *Education Workforce Data & Reports*. VDOE: Education Workforce Data & Reports. https://doe.virginia.gov/teaching/workforce_data/index.shtml

Virginia Department of Education (VDOE). (2022). *Safety Guide for Career and Technical Education*. Technology Education.

https://www.scorecard.doe.virginia.gov/instruction/career_technical/cte-safety-best-practice-guide.docx

Virginia Technology and Engineering Education Association (VTEEA). (2023). *Virginia Technology and Engineering Education Association.* VTEEA. https://www.vteea.org/

Vizzi, F. A., & Cardoso, A. (1951). *Industrial arts safety manual.* University of Tampa.

Vygotskǐ, L. S., & Cole, M. (1978;1980;). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Walan, S. (2021;2019;). The dream performance - a case study of young girls' development of interest in STEM and 21st century skills, when activities in a makerspace were combined with drama. *Research in Science & Technological Education, 39*(1), 23-43. https://doi.org/10.1080/02635143.2019.1647157

Washington, B. T. (1903, October 1). *Industrial Education for the Negro*. Teaching American History. https://teachingamericanhistory.org/document/industrial-education-for-the-negro/

Watt, M. G. (2011). The Common Core State Standards Initiative: An Overview. *Online submission*.

Webb, N. L. (2002). Depth-of-knowledge levels for four content areas. *Language Arts*, *28*(March).

Wells, J. G. (2016). I-stem ed exemplar: implementation of the proposal model. *Technology and Engineering Teacher*, *76*(2), 16–23.

White, H. (2011). Our education system is not so much "broken"-as it is totally outdated. *STEAM*, *16*, 2018.

Woodward, C. M. (1911). *Manual training in education*. Walter Scott.

Yip, W. Y. V. (2020, April). Developing undergraduate student teachers' competence in integrative STEM teaching. In *Frontiers in Education* (Vol. 5, p. 44). Frontiers Media SA.

Zhao, Y. (2012). Flunking innovation and creativity. *Phi Delta Kappan*, *94*(1), 56-61.

Zhao, Y. (2012). *World class learners: Educating creative and entrepreneurial students*. Corwin Press.

Zhao, Y. (2015). A world at risk: An imperative for a paradigm shift to cultivate 21st century learners. *Society*, *52*(2), 129-135.

Zhao, Y. (2016). From deficiency to strength: Shifting the mindset about education inequality. *Journal of Social Issues*, *72*(4), 720-739.

Zhao, Y. (2017). What works may hurt: Side effects in education. *Journal of Educational Change*, *18*(1), 1-19.

Zhao, Y. (2020). COVID-19 as a catalyst for educational change. *Prospects*, *49*(1), 29-33.

Zhao, Y. (2020). Two decades of havoc: A synthesis of criticism against PISA. *Journal of Educational Change*, *21*(2), 245-266.

Appendix A IRB Approval

LIBERTY UNIVERSITY
INSTITUTIONAL REVIEW BOARD

June 5, 2023

George Cornwell
Charlotte Holter

Re: IRB Exemption - IRB-FY22-23-1529 Exploring 21st Century Learning in Virginia Secondary School Technology and Engineering Classrooms: A Hermeneutic Phenomenological Study

Dear George Cornwell, Charlotte Holter,

The Liberty University Institutional Review Board (IRB) has reviewed your application in accordance with the Office for Human Research Protections (OHRP) and Food and Drug Administration (FDA) regulations and finds your study to be exempt from further IRB review. This means you may begin your research with the data safeguarding methods mentioned in your approved application, and no further IRB oversight is required.

Your study falls under the following exemption category, which identifies specific situations in which human participants research is exempt from the policy set forth in 45 CFR 46:104(d):

Category 2.(iii). Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met:
The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by §46.111(a)(7).

Your stamped consent form(s) and final versions of your study documents can be found under the Attachments tab within the Submission Details section of your study on Cayuse IRB. Your stamped consent form(s) should be copied and used to gain the consent of your research participants. If you plan to provide your consent information electronically, the contents of the attached consent document(s) should be made available without alteration.

Please note that this exemption only applies to your current research application, and any modifications to your protocol must be reported to the Liberty University IRB for verification of continued exemption status. You may report these changes by completing a modification submission through your Cayuse IRB account.

If you have any questions about this exemption or need assistance in determining whether possible modifications to your protocol would change your exemption status, please email us at irb@liberty.edu.

Sincerely,
G. Michele Baker, PhD, CIP
Administrative Chair
Research Ethics Office

Date: 11-3-2023

IRB #: IRB-FY22-23-1529
Title: Exploring 21st Century Learning in Virginia Secondary School Technology and Engineering Classrooms: A Hermeneutic Phenomenological Study
Creation Date: 5-7-2023
End Date:
Status: Approved
Principal Investigator: George Cornwell
Review Board: Research Ethics Office
Sponsor:

Study History

Submission Type	Initial	Review Type	Limited	Decision	Exempt - Limited IRB

Key Study Contacts

Member	Charlotte Holter	Role	Co-Principal Investigator	Contact	
Member	George Cornwell	Role	Principal Investigator	Contact	
Member	George Cornwell	Role	Primary Contact	Contact	

Appendix B Informed Consent

Consent

Title of the Project: Exploring 21st Century Learning in Virginia Secondary School Technology and Engineering Classrooms: A Hermeneutic Phenomenological Study
Principal Investigator: George Nicholas Cornwell, Doctoral Candidate, School of Education, Liberty University

Invitation to be Part of a Research Study

You are invited to participate in a research study. To participate, you must be a current Virginia Secondary School (grades 6-12) Educator who teaches technology education, engineering education, or STEM class(es). Taking part in this research project is voluntary.

Please take time to read this entire form and ask questions before deciding whether to take part in this research.

What is the study about and why is it being done?

My research aims to understand how technology and engineering teachers use integrative STEM methodology and *The Standards for Technological and Engineering Literacy* to foster and assess 21st-century learning.

What will happen if you take part in this study?

If you agree to be in this study, I will ask you to do the following:

1. Individual Interview (60 minutes) – I will conduct a 19-question interview with each participant. Each interview will be audio and video recorded. I will handwrite notes as the interview occurs.
2. Journal Prompts (30 minutes) – Upon completion of the interview, participants will be asked to complete four journal prompts.
3. Physical Artifacts (15 minutes) – Participants will be asked to share non-traditional lesson planning materials used in 21st-century learning. Examples include seating charts, testing devices, jigs/fixtures, learning games, rules for competition, teacher websites, digital teaching portfolios, safety plans, accommodations for collaboration, etc.

How could you or others benefit from this study?

The direct benefits participants should expect from participating in this study include learning how fellow technology and engineering educators foster and assess 21st-century learning.

Benefits to society include identifying teaching and learning methods to revise antiquated curricula and preparing students for life in the 21st century.

What risks might you experience from being in this study?

The expected risks from participating in this study are minimal, which means they are equal to the risks you would encounter in everyday life.

How will personal information be protected?

The records of this study will be kept private. Published reports will not include any information that will make it possible to identify a subject. Research records will be stored securely, and only the researcher will have access to the records.

- Participant responses will be kept confidential by replacing names with pseudonyms.
- Interviews will be conducted in a location where others will not easily overhear the conversation.
- Data collected from you may be used in future research studies and/or shared with other researchers. If data collected from you is reused or shared, any information that could identify you, if applicable, will be removed beforehand.
- Electronic data will be stored on a password-locked computer. Hardcopy data will be stored in a locked file cabinet. After seven years, all electronic records will be deleted] and all hardcopy records will be shredded.
- Recordings will be stored on a password-locked computer for seven years and then deleted. The researcher and members of his doctoral committee will have access to these recordings.

Is study participation voluntary?

The researcher is a member of the Virginia Technology and Engineering Education Association (VTEEA). Participation in this study is voluntary. Your decision on whether to participate will not affect your current or future relations with Liberty University or the VTEEA. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

What should you do if you decide to withdraw from the study?

If you choose to withdraw from the study, please contact the researcher at the email address included in the next paragraph. Should you choose to withdraw, data collected from you will be destroyed immediately and will not be included in this study.

Whom do you contact if you have questions or concerns about the study?

The researcher conducting this study is George Nicholas Cornwell. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact him at [redacted]@liberty.edu. You may also contact the researcher's faculty sponsor, Dr. Charlotte Holter, at [redacted]@liberty.edu.

Whom do you contact if you have questions about your rights as a research participant?

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, **you are encouraged** to contact the IRB. Our physical address is Institutional Review Board, 1971 University Blvd., Green Hall Ste. 2845, Lynchburg, VA, 24515; our phone number is 434-592-5530, and our email address is irb@liberty.edu.

Disclaimer: The Institutional Review Board (IRB) is tasked with ensuring that human subjects research will be conducted in an ethical manner as defined and required by federal regulations. The topics covered and viewpoints expressed or alluded to by student and faculty researchers are those of the researchers and do not necessarily reflect the official policies or positions of Liberty University.

Your Consent

By signing this document, you are agreeing to be in this study. Make sure you understand what the study is about before you sign. You will be given a copy of this document for your records. The researcher will keep a copy with the study records. If you have any questions about the study after you sign this document, you can contact the study team using the information provided above.

I have read and understood the above information. I have asked questions and have received answers. I consent to participate in the study.

☐ The researcher has my permission to audio-record/video-record/photograph me as part of my participation in this study.

____

Printed Subject Name

____

Signature & Date

Appendix C ITEEA Copyright Approval

Technology and Engineering bring STEM to Life!
International Technology and Engineering Educators Association

1908 Association Drive, Suite C
Reston, VA 20191-1539
iteea@iteea.org
703.860.2100

November 17, 2023

To Whom it May Concern,

ITEEA grants George N. Cornwell permission to use and publish the *Basic Structures of Standards for Technological and Engineering* graphic on page 11 of *Standards of Technological and Engineering Literacy* (ITEEA, 2020).

Citation:

International Technology and Engineering Educators Association (ITEEA). (2020). *Standards for technological and engineering literacy: the role of technology and engineering in STEM education.* www.iteea.org/STEL.aspx

Please do not hesitate to contact me with any questions.

[redacted]

Kathleen B. de la Paz

Director of Communications

Appendix D Professional Educator Organizations

Table 1

Professional Educator Organization	Date Founded	Mission	Vision/Strategic Plan
Association for the Advancement of Computing in Education (AACE, 2022).	1981	Advancing Information Technology in Education and E-Learning research, development, learning, and its practical application.	None listed.
American Council on the Teaching of Foreign Languages (ACTFL, 2022).	1967	Providing vision, leadership and support for quality teaching and learning of languages.	ACTFL envisions an interconnected world where everyone benefits from and values a multilingual and multicultural education.
Association for Educational Communications and Technology (AECT, 2022).	1923	Provide international leadership by promoting scholarship and best practices in the creation, use, and management of technologies for effective teaching and learning.	We seek to be the premier international organization in educational technology, the organization to which others refer for research and best practices.

Table 1 Continued

Professional Educator Organization	Date Founded	Mission	Vision/Strategic Plan
American Federation of Teachers (AFT, 2022).	1916	The American Federation of Teachers is a union of professionals that champions fairness; democracy; economic opportunity; and high-quality public education, healthcare and public services for our students, their families and our communities. We are committed to advancing these principles through community engagement, organizing, collective bargaining and political activism, and especially through the work our members do.	None listed.
Association for Supervision and Curriculum Development (ASCD, 2022)	1947	Supporting the whole child is at the core of our mission and everything we do at ASCD.	None listed.

Table 1 Continued

Professional Educator Organization	Date Founded	Mission	Vision/Strategic Plan
American School Counselor Association (ACSA, 2022).	1952	To represent school counselors and to promote professionalism and ethical practices.	The American School Counselor Association (ASCA) is the foundation that expands the image and influence of school counselors through advocacy, leadership, collaboration and systemic change. ASCA empowers school counselors with the knowledge, skills, linkages and resources to promote student success in the school, the home, the community and the world.
Council for Exceptional Children (CEC, 2022)	1922	Cultivating, supporting, and empowering education professionals who work with individuals with disabilities by: • Advocating for education professionals and for individuals with disabilities, and/or gifts and talents • Advancing professional practice and scholarly research • Promoting diversity, equity, inclusivity, and accessibility • Building networks, partnerships, and communities	High-quality education that is inclusive and equitable for individuals with disabilities.

Table 1 Continued

Professional Educator Organization	Date Founded	Mission	Vision/Strategic Plan
International Society for Technology in Education (ISTE, 2022)	1979	ISTE inspires educators worldwide to use technology to innovate teaching and learning, accelerate good practice and solve tough problems in education by providing community, knowledge and the ISTE Standards, a framework for rethinking education and empowering learners.	All educators are empowered to harness technology to accelerate innovation in teaching and learning, and inspire learners to reach their greatest potential.
International Technology and Engineering Educators Association (ITEEA, 2022)	1939	To advance technological and engineering capabilities for all people and to nurture and promote the professionalism of those engaged in these pursuits. ITEEA seeks to meet the professional needs and interests of members as well as to improve public understanding of technology, innovation, design, and engineering education and its contributions.	By engaging all members of ITEEA and expanding partnerships, the new Strategic Plan increases our capacity to support and promote technology and engineering educators to lead Integrative STEM Education

Table 1 Continued

Professional Educator Organization	Date Founded	Mission	Vision/Strategic Plan
National Art Education Association (NAEA, 2022).	1947	The National Art Education Association (NAEA) champions creative growth and innovation by equitably advancing the tools and resources for a high-quality visual arts, design, and media arts education throughout diverse populations and communities of practice.	The National Art Education Association (NAEA) harnesses the power of the visual arts, design, and media arts to educate and enrich the lives of all learners and communities, especially those who are members of historically marginalized groups, and serves as a catalyst for developing creative and culturally competent future generations.
National Association for Music Education (NAfME, 2022).	1907	The mission of the National Association for Music Education is to advance music education by promoting the understanding and making of music by all.	None listed.
National Association for Gifted Children (NAGC, 2022).	1976	To empower all who support children with advanced abilities in accessing equitable opportunities that develop their gifts and talents. We do this through advocacy, outreach, education, and research.	All children have opportunities and support to realize their full potential.
National Business Education Association (NBEA, 2022).	1878	NBEA is committed to the advancement of the professional interest and competence of its members and provides programs and services that enhance members' professional growth and development.	None listed.

Table 1 Continued

Professional Educator Organization	Date Founded	Mission	Vision/Strategic Plan
National Council for Agricultural Education (NCAE, 2022).	1983	The Council leads the future of school-based agricultural education by: • Identifying opportunities and resources • Providing a forum for thought and direction Focusing on academic and career success for all students	The Council creates an intentional direction for the Agricultural Education Model by: • Connecting Leaders • Fostering Collaboration • Driving Action
National Education Association (NEA, 2022).	1857	Our mission is to advocate for education professionals and to unite our members and the nation to fulfill the promise of public education to prepare every student to succeed in a diverse and interdependent world.	Our vision is a great public school for every student.
National Parent Teachers Association (NPTA, 2022).	1897	To make every child's potential a reality by engaging and empowering families and communities to advocate for all children.	None listed.
Society of Health and Physical Educators (Shape America, 2022).	1885	To advance professional practice and promote research related to health and physical education, physical activity, dance and sport.	A nation where all children are prepared to lead healthy, physically active lives.