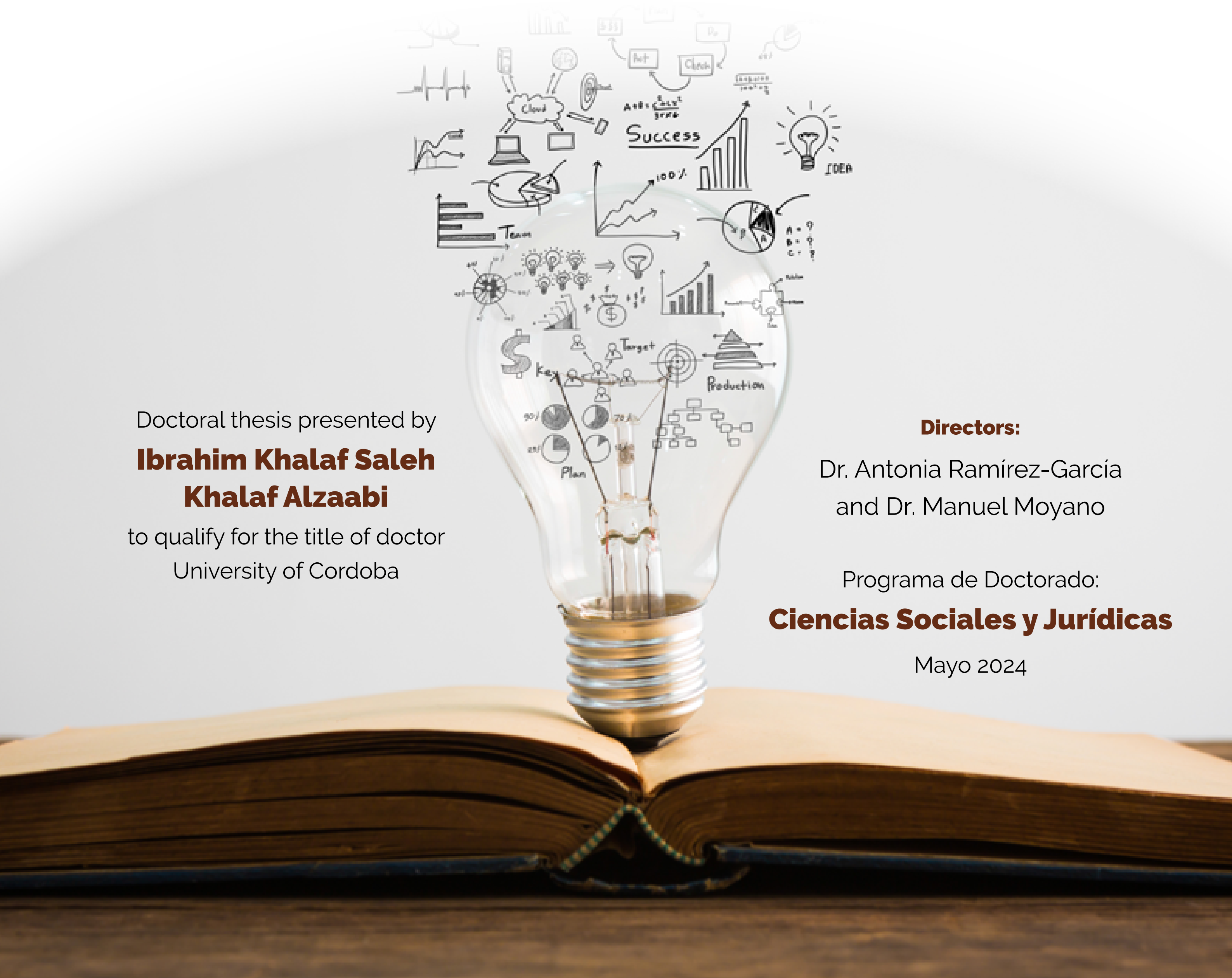
UNIVERSIDAD DE CÓRDOBA

# Using a project-based learning approach to foster interest in STEM subjects and the development of critical thinking in a vocational school in the UAE

## Utilización de un enfoque de aprendizaje basado en proyectos para fomentar el interés por las materias STEM y el desarrollo del pensamiento crítico en una escuela de formación profesional de los EAU





Doctoral thesis presented by

**Ibrahim Khalaf Saleh Khalaf Alzaabi**

to qualify for the title of doctor
University of Cordoba

**Directors:**

Dr. Antonia Ramírez-García
and Dr. Manuel Moyano


Programa de Doctorado:

**Ciencias Sociales y Jurídicas**

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TITULO: *Using a project-based learning approach to foster interest in STEM subjects and the development of critical thinking in a vocational school in the UAE*

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This thesis is dedicated to my grandfather, Jasim Saeed Alzaabi.

# ABSTRACT

Students need help developing critical thinking skills, and in many education systems, improvements are needed to the curriculum to ensure this essential capability is nurtured. The distinctive characteristics of modern digital natives makes this need even greater.

Although STEM project-based learning (PBL) has demonstrated success in improving students' proficiency in science, technology, engineering, and mathematics, there is a lack of research on how effective STEM education is in developing critical thinking skills at the university level.

To help fill this gap, the present research incorporated a quasi-experimental design to determine how PBL education in STEM disciplines taught in the United Arab Emirates affects the development of critical thinking skills. We conducted a STEM semantics survey and administered a recognized critical thinking test to 150 11$^{th}$ grade students. We also interviewed four teachers and three eleventh-grade students.

The research found that PBL promotes critical thinking in STEM disciplines, by providing students with real-life experiences. By engaging in PBL, students were able to broaden their knowledge and satisfy their curiosity. Despite several limitations, including survey restrictions posed by the COVID-19 pandemic, the findings contribute to our understanding of critical thinking education in the UAE. Further, the research findings and the developed framework of key characteristics can be used by teachers and researchers to promote the implementation and design of PBL science education.

# ACKNOWLEDGEMENTS

It is with sincere gratitude that I extend thanks to my supervisors, Professor Antonia Ramírez-García and Professor Manuel Moyano, who provided me with invaluable guidance, unwavering support, and extraordinary forbearance throughout my PhD research. My academic research and personal development have benefitted greatly from their knowledge and experience. Furthermore, I would like to thank Professor Abdullatif Al Shamsi, HCT President and CEO in the UAE; Dr. Ahmad Abdulmanan Alawar, ATHS Managing Director; and Kareem Ragab ATHS Principal, for their academic and technical assistance. The support they have provided has been instrumental to my professional growth.

Living and studying at the University of Cordoba has been gratifying, and I am grateful to all the members of the university for their kindness and support.

To conclude, I am indebted to my parents, my wife, and my children for their unwavering support and encouragement. It would not have been possible for me to finish my studies without their invaluable support.

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ACTVET: | Abu Dhabi Centre for Technical and Vocational Education and Training |
| ADVETI: | Abu Dhabi Vocational Education and Training Institute |
| AI: | Artificial Intelligence |
| HCT: | Higher Colleges of Technology |
| IAT: | Institute of Applied Technology |
| MOE: | Ministry of Education |
| PBL: | Project-Based Learning |
| STEM: | Science, Technology, Engineering, Mathematics |
| TVET: | Technical and Vocational Education and Training |
| UAE: | United Arab Emirates |
| UAEU: | United Arab Emirates University |

# OVERVIEW

The general structure of the thesis is presented below.

Chapter 1 examines the effects of the Fourth Industrial Revolution (4IR) on STEM careers. Specifically, it discusses how 4IR is changing the world, and how vocational education must adapt to these changes in the workplace. Chapter 2 to provide a historical background for the STEM concept and discuss the necessity for STEM education in the UAE. Chapter 3 forms the theoretical groundwork of the research. Specifically, we discuss the importance of Project-Based Learning (PBL) and STEM education in developing critical thinking skills among students. An explanation is given of how PBL and STEM can be integrated with modern teaching strategies for students to experience a more engaging and interactive learning experience. Chapter 4 reveals the research's purpose, providing insight into the aim that drives the research endeavour. Moreover, the chapter explains why the research is important and how it addresses existing gaps in Project-Based Learning and critical thinking. In Chapter 5, we provide a comprehensive introduction to the philosophical foundations of this research and the research design. Additionally, the chapter provides an overview of the sampling process and the instruments used. The chapter concludes with a discussion of ethical considerations. Chapter 6 presents the planning and implementation of the project-based learning experience, specifying its design and elements. Chapters 7 and 8 offer an in-depth look of the methods used for data collection, the analysis and interpretation of the results, and how they relate to the quantitative (Study 1) and qualitative (Study 2) components of the research. Finally, a comprehensive summary of the research findings is presented in Chapter 9.

# SECTION I
## THEORETICAL FRAMEWORK

### CHAPTER 1.
### CAREERS FOR A NEW SOCIETY

Innovation and transformation are spawning a range of new employment categories that demand a unique set of abilities (Govindarajan & Srivastava, 2022). Several technological advancements have resulted in profound changes to economic systems and social structures. Numerous facets of our society are being dramatically impacted by the technological revolution, as robots and artificial intelligence are replacing humans in several positions (Dahlin, 2022). Some career fields will observe significant reductions in employment opportunities for humans in the future, while others will expand, and some will become even more prevalent than they are today (Govindarajan & Srivastava, 2022). The COVID-19 pandemic accelerated this timeline. Future workers will need to possess a skill set commensurate with the increasing rate of technological progression (Hodder, 2020). Malele and Ramaboka (2020) predict that in the near future, there will be a greater use of information and communication technology (ICT) and a new educational approach that emphasizes science, technology, engineering, and mathematics (STEM). For future generations to remain competitive, they will need skills in STEM disciplines.

#### 1.1. Fourth Industrial Revolution in the UAE

The Fourth Industrial Revolution (4IR) describes the present epoch of technological progress marked by the merging of physical, digital, and biological systems (World Economic Forum, 2023). This involves the incorporation of cutting-edge technologies such as artificial intelligence, robotics, the Internet of Things (IoT), nanotechnology, biotechnology, and quantum computing, among others, which are transforming the way people live, work, and interact (McGinnis, 2023). The Fourth Industrial Revolution is expected to bring significant advancements across various domains of society, including healthcare (Lee & Lim, 2017), education, manufacturing, and transportation.

The UAE aims to strengthen its position as a worldwide gateway through its Fourth Industrial Revolution Strategy (UAE, 2023). In addition, the UAE hopes to boost its contribution to the national economy through investing in innovation and future technology (United Arab Emirates Ministry of Industry & Advanced Technology, 2023). The UAE seeks to become a global leader in embracing cutting-edge technology to benefit society, promote happiness, and insure sustainability (UAE, 2022). Providing an example of a sustainable city powered by artificial intelligence to the world is a means through which the UAE can serve as a model for achieving sustainability – an important component of the country's strategy (UAE, 2023). This goal will be achieved by prioritising several essential domains, including education (Hazlegreaves, 2020), artificial intelligence (Oosthuizen, 2022), and genetic medicine.

The development of innovative education in a supportive learning environment will be equally beneficial to science, nanotechnology, and artificial intelligence. Intelligent and tailored genomic medicine will contribute to the advancement of customized medical technology, while also strengthening the UAE's position as a worldwide hub for healthcare. A critical element of improving telemedicine and developing cutting-edge medical solutions, such as implantable and wearable devices, is the use of robotics and nanotechnology research (UAE, 2022).

Education plays a major role in the UAE's approach to the Fourth Industrial Revolution (WAM, 2017), during which augmented learning will be used to enhance educational outcomes and to meet the technological demands of the future (Saif et al., 2021). In addition, as part of the strategic plan, future generations will be equipped with sophisticated scientific and technological abilities, and a system of applied education will be built to prepare them for the Fourth Industrial Revolution by establishing a national talent pool (UAE, 2022).

## 1.2. Employability in the Fourth Industrial Revolution

The employability of young people is an increasingly important research topic (Awad, 2020; Moore & Khan, 2020; Nikunen, 2021), particularly as the Fourth Industrial Revolution transforms the foundation of work, employment, and business (Bikse et al., 2022). With advances in technology, the distinction between humans and robots is becoming blurred, and routinely repetitive tasks are being gradually phased out by creative thinking and adaptive learning (Gaudin, 2014). The advent of automation and robotic technology has posed a significant threat to various occupational groups, from accountants to taxi drivers (Bikse et al., 2022).

In today's highly competitive job market, employability skills have become essential for young people to succeed. These skills, which encompass both soft and practical abilities, enhance productivity and employability by equipping individuals with the necessary tools to excel in their careers. Fajaryati et al. (2020) note that employers seek candidates who possess not only technical skills but also excellent communication, collaboration, problem-solving, and critical thinking abilities, all of which fall under the umbrella of employability skills.

However, many young people still lack practical skills, preventing employment (PWC, 2022). In comparison with the global average of 65 percent, the Middle East and North Africa (MENA) region only realizes 62 percent of its human capital potential. This percentage ranges from 73 percent to 68 percent in high-income countries such as Bahrain, Qatar, and the UAE. The absence of technical and vocational education and training (TVET) exacerbates the lack of soft skills, sector-specific skills, and functional skills, which in turn hinders productivity and employability by not adequately equipping individuals with the necessary soft and practical abilities needed to succeed in the labour market (Rivera et al., 2022).

### 1.3. Fourth Industrial Revolution on vocational skills

Spottl and Windelband (2021) observe that despite the significant impact of the Fourth Industrial Revolution on education and training, little attention has been given to its potential and actual impacts. Knowledge-based economies such as the UAE are propelled by competence and creativity (UAE Vision, 2018). It has been suggested by Gaudin (2014) that technological advancements that blur the boundaries between physical, digital, and biological realms have contributed to the emergence of the Fourth Industrial Revolution (4IR) and introduced a novel paradigm for living, working, and interacting. As human activities grow, there are both hopes and fears, as well as reservations regarding the economic consequences and a potential rise in inequality that may be a product of these incumbent changes (Kayyali, 2022). To increase worker productivity and boost national competitiveness, it's necessary to incorporate new technologies (Venturini, 2022).

Yet this presents a Catch-22 for employability. With the advent of new technologies and automation, the nature of work has changed dramatically (Oosthuizen, 2022), and it's increasingly evident that individuals necessitate occupational competencies that are pertinent to the contemporary labour market. These include digital literacy, coding, data analysis, artificial intelligence, and robotics, among others (Akther, 2022). This will result in substantial job losses, but will also create new career opportunities (Nunes, 2021). To achieve these benefits, organisations must increase their investments in skills training and employee development.

Technical and vocational education and training (TVET) as well as skills development play a crucial role in equipping young individuals with the necessary competencies for their future professional endeavours (Matthews & Arulsamy, 2019). The absence of industry applicability and substandard quality in TVET programmes could potentially impede the acquisition of skills necessary for fostering economic growth. According to Joshi and Patankar (2022), there is a pressing need to modify TVET to align it with the demands of the Fourth Industrial Revolution. Moreover, Spöttl and Windelband (2021) argue that vocational education assumes a significant function in fostering industrial expansion and facilitating the generation of employment opportunities.

While the current industrial revolution threatens specific jobs, Bikse et al. (2022) and Sudira (2018) suggest this trend could foster creative employment, but only if vocational school curricula is adjusted. As the authors explain, these changes are inevitable, and vocational education must play a proactive role in boosting human capital development. Moreover, Ferm (2021) recommends that the curriculum for vocational, education, and training (VET) include real-world challenges and applications that may be used to assess the skills and competencies of the workforce (Alhloul & Kiss, 2022).

Deloitte Manufacturing Institute (Deloitte Insights, 2018) revealed that skills required for these jobs will include welding, manufacturing, operating machinery and tools, and the ability to think critically. These are all relatable skills in technical and vocational education. Since there is a skills shortage in vocational jobs, the UAE and other Gulf countries are experiencing an influx of foreigners who are qualified to fill these positions (Property Finder, 2023). In the Middle East and North Africa (MENA), employment opportunities for local citizens are limited due to the influx of expatriates into both the private and public sectors (Kantaria & Vesuvala, 2018). The UAE must therefore continue with Emiratisation in order to create opportunities for university graduates both in the public and private sectors. In this way, the UAE's dependence on expatriate workers in their labour force can be reduced (Haak-Saheem & Brewster, 2017).

Appropriate skills are needed to successfully integrate young people into the labour force. Baumeler (2019) argues that formal education and training are the cornerstones on which skills development is built. Thus, the answer lays in technical and vocational education and training, a deliberate intervention to enhance learning that would make people more relevant and productive in areas such as business and technology.

In their research, Afeti and Adubra (2012) provide evidence to support the notion that TVET has emerged as an effective approach in Africa for cultivating human capital and furnishing the technical labour force with vital competencies. The authors highlight that TVET caters to the requirements of both employers and students, equipping them with the necessary skills for gainful employment and fostering a lifestyle that promotes well-being. Furthermore, the authors argue that TVET education has the necessary resources and capabilities to effectively educate Africa's workforce and cultivate innovation. This, in turn, promotes economic prosperity by providing opportunities for individuals to overcome poverty. The authors propose the alteration of vocational education to effectively cater to the unique requirements of persons from various socioeconomic backgrounds. Based on the authors' research findings, it is argued that TVET have a significant impact on promoting industrial and economic development.

There are still gaps in the TVET application. For instance, the European Centre for the Development of Vocational Training asserts that research on vocational education integrating theoretical learning with practical training for the development of skills remains in its infancy (Lettmayr & Riihimäki, 2011). Valdés (2017), meanwhile, identified a mismatch between vocational education training needs and vocational curricula. Based on survey design and focus groups, the author collected data to determine the type of curriculum development that would be beneficial for aviation students. The study participants expressed that certain vocational subjects, such as information and communication technology maintenance and air traffic control were inadequately recognized within aviation education.

Baqadir et al. (2011) examined attitudes of stakeholders toward the vocational training of Saudi graduates. The authors found that employers had reservations about hiring Saudi nationals. In Baqadir et al. (2011), employers identified three areas of vocational education for improvement, namely "work ethics, specialised knowledge and generic skills".

In a study that investigated employability skills gained through vocational learning, authors defined employability skills as a set of essential skills for creating a successful workforce (Kazilan, Hamzah, & Bakar, 2009). The sample was drawn from 250 final year students at 12 technical and vocational establishments. The results indicated that most participants felt that the curriculum failed to equip them with sufficient skills to secure their future. Students also displayed weaknesses in mathematics and reasoning abilities that were not in line with employers' expectations. Given these findings, technical, and vocational training institutions may need to collaborate with employers to identify and close employee skills gaps.

As the global economy has undergone significant changes over the past few decades, industries are increasingly using technological innovations to increase productivity and efficiency. This shift has resulted in an increase in the demand for skilled professionals who possess the technical knowledge necessary to operate and maintain sophisticated equipment and systems.

The demands for vocational education and training have increased in parallel, and many countries have implemented policies to promote and support the needed changes. By integrating technical and soft skills training – such as communication, teamwork, and problem-solving abilities – vocational education programs can produce graduates who are prepared to meet the demands of the current, and future, job market.

## 1.4. (De)-stigmatising vocational education

The stigmatisation of vocational education is premised upon the observation that professional occupations place a higher value on professional skills than skills acquired through vocational education (Aldossari, 2020). Lee and Comello (2019) and Wigfall (2017) suggest that vocational education is stigmatised due to "cultural bias." This bias is associated with the tendency to idealise four-year university degrees and the belief that such degrees will enhance employment prospects (Lee & Comello, 2019).

The negative perception regarding vocational education is referred to by scholars in Ghana as a stigma resulting from ignorance (Nutassey, Quayson, & Agyei-Boakye, 2014). The authors observed that people in Ghana remain ignorant of the relevance of technical and vocational education and training and its role in developing skills and creating job opportunities. Thus, the belief remains that TVET is only suitable for students who aren't academically inclined enough to qualify for university admission.

For instance, the authors investigated stigma surrounding carpentry courses in vocational institutions in the country, targeting students who were potential research participants in technical and vocational institutions. The authors found that students stigmatised carpentry, which led them to recommended that misperceptions surrounding vocational education should be identified at an early age to help change societal views on vocational work. Similar findings were noted by Essel et al. (2014).

The stigmatisation of vocational education qualifications is not isolated to Ghana. In the United Kingdom, this issue was addressed during a briefing from the House of Lords in which the government was asked to provide support for vocational education systems, and the stigmatisation thereof was also mentioned (House of Lords, 2019).

Researchers have focused on methods for improving the public image and perception of vocational skills education. Chankseliani et al. (2016) concentrated on developing strategies to entice students to enrol in vocational schools. The authors took an introspective look at the best practices of vocational and technical training as opposed to researching the stigmatization of vocational education. For instance, the authors referenced World Skills, an international competition that tests the vocational skills of young people aged 18 to 21. Approximately 53 countries participate in the competition, and it has grown greatly in popularity. In 2017, when the competition was held in Abu Dhabi, 1,300 competitors from 59 countries showcased their vocational skills in technology, robotics, animation, graphic design, carpentry, automotive technology, fashion design, jewellery design, and hairdressing. The competition is intended to promote vocational training on a world class platform (World Skills, 2017).

Still, while vocational competitions might positively affect the perception people have of vocational training, personal beliefs and attitudes toward vocational education negatively impact students who are in the process of acquiring vocational qualifications. For instance, Mullan (2016) found that the stigmatization of vocational education remains pervasive in the UAE.

Bridging the skills gap can help (Adullah et al., 2015). Since vocational education focuses on job specific skills and can thus potentially alleviate the labour force deficit, it may create a brighter future for students enrolling into technical and vocational institutions.

The large number of expatriates in the labour force of the UAE and other Gulf countries make it incredibly difficult for host countries to secure jobs for their own citizens (World Economic Forum, 2017). To ensure future jobs for Emirati students, the UAE implemented a nationalisation programme that is also being followed by other Gulf countries (Khan & Saxena, 2022). Known as Emiratisation, the goal is to introduce UAE nationals into public and private sector labour forces (WAM, 2022), and over time, reduce the number of foreign workers in the UAE to help address youth unemployment (UAE, 2021). But much work remains. For every Emirati student completing their university degree, 10 Emiratis with vocational expertise are needed to build the country's knowledge economy (UAE,2022).

Despite persistent doubts about technical and vocational education standards, the UAE is actively investing in its improvement. The government gives priority to the development of competencies aligned with current and future technologies. It is striving to promote equitable access to reasonably priced tertiary and vocational education. The ultimate objective is to substantially enhance the proportion of young individuals and adults possessing technical and vocational expertise, sufficient education, suitable employment opportunities, and entrepreneurial skills.

## 1.5. Technical and vocational education in the UAE

Global interest in technical and vocational education and training (TVET) has led to the implementation of national education agendas in many countries (Akojee, 2016; UAE, 2023), including the UAE (UAE Vision, 2018), and significant attention is being paid to developing young people's skills in technical and vocational fields. The UAE acknowledges that TVET is essential for meeting the employment challenges driven by innovation, and is prioritizing vocational skills as a means to increase Emirati employability. As part of its commitment to developing future global citizens with world-class education, the UAE recognizes several types of TVET qualifications to support those embarking on a career, pursuing higher education, or simply looking to improve their skills. These include:

### 1.5.1. National Qualifications (NQ)

In National Qualifications, the learning objectives for the qualification are recognised as having been met by the students. According to the National Recognised Development Committees (NRDCs), the NQ serves as the National Occupational Qualifications Standards (NOSS). Stakeholders and industry experts are represented on these committees. NOSS is a performance specification determined by industry and endorsed by NQA (see below). The requirements for successful employment in the UAE are identified by the outline of necessary knowledge, skills, and abilities, and monitored by registered training providers, as governed by the country's Knowledge & Human Development Authority (n.d.).

### 1.5.2. National Recognised Qualifications (NRQ)

National Recognised Qualifications (NRQs) are accredited under the National Qualification Framework (QF Emirates). NRQs are similar to NQs in that they are based on consultation and commitment to the industry and are designed to identify deficits in the UAE labour market. The UAE provides NRQs through licensed TVET providers. In Dubai, all NQs issued by TVET providers are subject to internal assessments and internal audits by the Quality Assurance Department (QAD). QAD verifies student certifications externally. Qualifications can also be internationally accredited if both QAD and an accredited international accreditation body have qualifications with comparable standards (Knowledge & Human Development Authority, n.d).

### 1.5.3. International Accredited Qualifications recognised in the UAE

A qualification that is recognised in the country of origin is an international qualification. It was established under the auspices of the National Qualifications Authority (National Qualifications Authority, 2011) to manage and organise the vocational, technical, and professional educations and training sectors within the UAE. Internationally accredited qualifications are nationally recognised in the UAE through the alignment process. Certificates are issued by qualified and/or awarding bodies from other countries at the level of the QF Emirates. Internationally approved qualifications in Dubai are assessed based on the criteria set forth by the International Awarding Body (IAB) and are subject to internal review by their Technical-Vocational Education and Training (TVET) provider. Furthermore, they are subject to external quality control measures conducted by their international awarding authority and the Quality Assurance Department. The IAB designates an external verifier for student certification, and the QAD issues a declaration of recognition. Moreover, because these certificates meet the standard criteria of the National Qualifications Authority (NQA) and Vocational Education and Training Awards Council (VETAC) (Knowledge & Human Development Authority, n.d.). VETAC functions as a governmental supervisory and regulatory body. Its tasks include planning, quality control checks, and inspections to ensure that vocational qualifications provided by awardees and registered training providers are in line with standards, policies, and procedures through:

- The development of policies, standards, and regulations related to TVET.
- The development of occupational standards, qualifications, and programmes in accordance with government regulations, policies, and procedures.
- Assuring that occupational standards and vocational qualifications are in accordance with established criteria and procedures.
- Providing recommendations and suggestions on how TVET can be improved in the UAE.
- Approval of the awarding body's regulations, criteria, and procedures.
- Developing national occupational standards through the establishment of sectoral councils and committees (Ministry of Education, 2016).

## 1.6. **Governing bodies involved in the regulation of TVET in the UAE**

The Abu Dhabi Centre for Technical and Vocational Education and Training (ACTVET), Abu Dhabi Vocational Education and Training Institute (ADVETI), and the Institute of Applied Technology (IAT) are responsible for ensuring that technical and vocational training institutions adhere to the high standards set out by the UAE Ministry of Education (Ministery of Education, 2016).

### 1.6.1. Abu Dhabi Centre for Technical and Vocational Education and Training (ACTVET)

The Abu Dhabi Centre for Technical and Vocational Education and Training (ACTVET). primary responsibility is to establish and enforce policies and standards to govern technical and vocational educational institutions effectively. In addition, ACTVET licenses trainers and tutors who meet local UAE market requirements. The centre aims to enhance education and training opportunities for young Emiratis within the Emirates' qualifications framework. ACTVET strives to increase the number of qualified Emiratis pursuing rewarding career paths and promoting lifelong personal development. To achieve these goals, ACTVET oversees the Abu Dhabi Vocational Education and Training Institute and the Abu Dhabi Institute of Applied Technology, both offering certified educational and vocational training programmes in line with global best practices, preparing students for the global economy (ACTVET, 2021).

### 1.6.2. Abu Dhabi Vocational Education and Training Institute (ADVETI)

Established in 2007, the Abu Dhabi Vocational Education and Training Institute (ADVETI) comprises five institutions: the Abu Dhabi Al Jazirah Institute of Science and Technology; the Al Jaheli Institute of Science and Technology; the Baynounah Institute of Science and Technology; the Secondary Technical Schools (STS); and the Al Reef Institute of Logistics and Applied Technology in the Al Shahama Region. ADVETI is authorised by the Ministry of Higher Education and Science Research and has received accreditations for all its courses, with plans to obtain national accreditation for new programmes. ADVETI offers a diverse range of certifications and diplomas, including qualifications in business, information technology, travel and tourism, environmental studies, industrial technology, logistics, and engineering. A foundation programme is also available for students who don't meet entry requirements. ADVETI's programmes were developed in consultation with Abu Dhabi industries and businesses to ensure that graduates are well-equipped to meet prospective employers' requirements and secure employment (Abu Dhabi Vocational Education and Training Institute, 2022).

### 1.6.3. Institute of Applied Technology (IAT)-ACTVET

The Institute of Applied Technology (IAT) (Figure1) was established by the Government of Abu Dhabi to promote career-oriented technology, recognising that education and training are crucial for personal development, increasing competitiveness, employment income, and promoting economic and social participation. IAT provides secondary and tertiary technology education in English with modern facilities and exceptional support services. There are also advanced programmes available at the institute in the fields of aviation, logistics, and nursing. IAT operates 20 campuses across Abu Dhabi, Al Ain, Dubai, and Sharjah, in addition to 14 vocational high schools, the Fatima College of Health Sciences, and two polytechnic institutes (Institute of Applied Technology, 2022).

Figure 1 shows the outside of the main building in Abu Dhabi where the Director of the Applied Technology High Schools is based. The current research is part of Applied Technology High Schools.

Figure 1. *Institute of Applied Technology*


Source: *World Teachers International Education Recruitment Polytechnic Institutes*

According to Abu Dhabi Polytechnic (n.d.), the institution was established in 2010 to support the Abu Dhabi Economic Vision 2030 by providing the UAE with a skilled industrial workforce across various technology and engineering disciplines. The institution adopts the German dual learning system and emphasises advanced technology over traditional academic curriculum. To prepare students for the workforce, an integrated training program combining advanced education and onsite training has been implemented. Abu Dhabi Economic Vision 2030 aims to transform the Emirates' economic base and promote global integration and long-term benefits for all. This vision serves as a roadmap for the development process and outlines the framework and content necessary to achieve the vision. To ensure precision in the execution of the policies and initiatives outlined in the 2030 Economic Vision, a series of five-year and annual economic plans will be developed by the Abu Dhabi Government (Abu Dhabi Polytechnic, n.d.).

## 1.7. Summary

Chapter 1 provides an introductory overview, highlighting the significant impacts brought about by the Fourth Industrial Revolution. In this particular context, the chapter provides a comprehensive analysis of the crucial necessity of providing students with practical, vocational skills in order to augment their employability within a constantly changing work market. Chapter 1 underlines the importance of technical and vocational education in preparing students for the challenges and opportunities of the future by emphasising the requirement of adjusting educational paradigms to meet the demands of the Fourth Industrial Revolution. Moreover, the chapter promotes the destigmatisation of vocational education, questioning antiquated beliefs and advocating for the importance of practical learning opportunities. In the specific context of the United Arab Emirates, where there is a strong emphasis on enhancing technical and vocational education, Chapter 1 presents a persuasive argument for allocating resources towards pioneering educational methodologies that prioritise the cultivation of skills and preparedness for the labour market. Chapter 1 serves as the foundation of this research, which will explore the interrelated areas of STEM education, Project-Based Learning, and the development of critical skills. It offers a framework for comprehending the transformative power of education in the era of the Fourth Industrial Revolution.

# CHAPTER 2.
# THE NEED FOR STEM EDUCATION IN THE UAE

As the Fourth Industrial Revolution picks of steam, STEM-related occupations are expected to grow faster than non-STEM occupations, making it imperative that vocational education and training reflects this shift in its curriculum. VET STEM-based programmes provide hands-on training in technical fields, including robotics, artificial intelligence, and advanced manufacturing. By integrating STEM into VET programmes, students will have a greater chance of obtaining well-paying, in-demand positions, as well as a better understanding of technological change.

This chapter will provide historical background for the science, technology, engineering, and mathematics concept, and discuss the necessity for STEM education in the UAE.

## 2.1. Historical background and implementation challenges of STEM

STEM education became essential in the 1950s, when, after Russia launched its Sputnik satellite, the United States attempted to differentiate itself in the field of science and technology (Powell, 2007). In other words, the space race established the framework for science education (Abrahamson & Wilensky, 2007). A new US science curriculum was created with nearly $1 billion from the National Defence Education Act of 1958. Most NDEA funds were awarded to students with exceptional academic credentials, particularly those seeking positions in scientific and technological fields (Jolly, 2009).

Over the next few decades, science and technology were increasingly integrated into the classroom. To address this trend, the US National Science Foundation created a program called SMET (science, mathematics, engineering, and technology). However, due to negative feedback and a reassessment, SMET was later replaced with STEM (Sanders, 2009). Since the 1990s, several educational organisations, such as the National Council of Teachers of Mathematics and the National Science Education Standards, have developed guidelines and standards to assist students in comprehending STEM-related concepts (Porter, 1994).

According to Lyons (2020), the history of STEM in the United States illustrates how an acronym can propel an unclear concept to the forefront of global education policy. Nowadays, STEM is frequently referenced in policy statements (U.S. Department of Education, n.d.; United Nations, 2022), news articles (Bauld, 2023; Moukayed, 2018), academic conferences (IEEE, 2023), and scholarly publications (Alzaabi et al., 2021; Li et al., 2020). However, the definition of STEM remains ambiguous and varies depending on the context and audience (Akerson, et al., 2018); Blackley & Howell, 2015; Li et al., 2020). It has become increasingly evident that STEM encompasses numerous academic disciplines, occupations, and professions that are related to science, technology, engineering, and mathematics (Lyons, 2020). Additionally, there was initially confusion between STEM and stem cell research, which persisted until Virginia Tech's Technology and Education Programme developed a STEM graduate program in 2005, leading to a surge of funding for STEM-related endeavours (Sanders, 2009).

STEM is usually ambiguous, even for practitioners (Sanders, 2009). The unclear implications of STEM, particularly at the classroom level, are leading to uncertainty and resistance to STEM's implementation in schools (Marrero et al., 2014). As Lyons (2020) describes, STEM confusion exists when STEM interpretations are creatively applied to real-world problems. Unlike traditional science and mathematics education, STEM focuses on teaching students how to apply logical reasoning to everyday life (Hom & Dobrijevic, 2022). Even Sanders (2009) acknowledged that STEM continues to pose several uncertainties. The author reiterates that technology educators claim the T (technology) and E (engineering) in STEM, whereas vocational and technical educators also claim the E. The author argues that the term "STEM" is often misused by educators, and it would be more appropriate to refer to it as "STEM education." Without the inclusion of "education," STEM simply refers to the fields in which scientists, engineers, and mathematicians work. From the author's perspective, individuals who teach science, mathematics, and technology should be considered STEM educators. It is therefore necessary to separate STEM education from other fields of study.

For Siekmann and Korbel (2016), deconstructing STEM and its components improves understanding; it can be compared to a building's roof, which is built on a foundation of core life skills such as literacy and numeracy. Through socio-emotional qualities such as inquisitiveness and resilience, an individual's sense of agency and self-efficacy can be increased at all phases of their educational or occupational growth. Instruments are accessible for use in educational, vocational, and industrial contexts across this STEM "shed" to categorize and evaluate skill levels and outcomes. Scientific work, for example, necessitates both logical reasoning and analytical abilities. Even though these traits are not directly related to STEM, they are all vital components of it. Deconstructing STEM allows one to accomplish the desired results of STEM education, such as equal measurement, career advising, and productivity (Siekmann & Korbel, 2016).

As noted, the definition of STEM has been subject to inconsistencies (Manly et al., 2018; Siekmann & Korbel, 2016). However, the integration of STEM education into curricula is an entirely separate matter (Roehrig et al., 2021). It requires careful planning and consideration of various factors, such as the availability of resources, teacher training, and alignment with learning objectives. Additionally, the implementation of STEM education may face challenges, such as resistance to change and the need for a significant shift in teaching pedagogy. Therefore, the successful integration of STEM education into national educational models requires a comprehensive approach that addresses all these factors and challenges.

## 2.2. STEM Challenges

According to Siekmann and Korbel (2016), STEM advocates often claim that there's a shortage of the necessary STEM competencies and knowledge. The authors suggest that education and training are necessary to ensure a sufficient workforce in the future. However, they claim that reliable labour market predictions are difficult to produce, due to the increasing nature of the workforce, and the transformation of the workforce and industry. To address the growing demand for STEM education, primary and secondary school educators across the globe should integrate STEM curricula and teaching methodologies into their teaching practices (Kelley & Knowles, 2016; Liu, 2020).

There's little question that STEM education develops 21st-century-relevant skills that prepare learners for future careers (Sen et al., 2018, p. 81). Still, research has found that, despite the potential long-term advantages of pursuing STEM subjects for current students in both schools and universities, there is a noticeable lack of enthusiasm for these subjects. This has been demonstrated in various studies which have attempted to inspire students to pursue careers in STEM fields (Drymiotou et al., 2021; Makarova et al., 2019; Baucum and Capraro, 2021). The following section discusses challenges related to STEM integration, curriculum, assessment, training, and stereotyping.

### 2.2.1. STEM disciplinary integration

STEM education is an interdisciplinary approach to learning that removes the traditional barriers that separate the four disciplines of science, technology, engineering, and mathematics, and integrates them into meaningful experiences for students (Hoachlander & Yanofsky, 2011). The problem is that integrating STEM programmes can be challenging (Gao et al., 2020), and some of the new instructional methods may not be compatible with existing school systems (Dong et al., 2020; Margot & Kettler, 2019). As Nadelson and Seifert (2017) claim, most STEM programmes are more influenced by teachers' ideas, knowledge, and pedagogical practices than standards. As part of the STEM integration process, knowledge and processes from various STEM domains are simultaneously integrated, without consideration of their respective disciplines. This results in multiple viable solutions to poorly organised problems that require skills and techniques drawn from several STEM disciplines (Nadelson & Seifert, 2017).

Integration is especially important when complex policy and economic, social, and environmental issues require interdisciplinary and integrated solutions (Sanders, 2009). With STEM integration, it is common to use terminology such as "integrated" (English, 2016), "interdisciplinary" (Mayes et al., 2018), and "transdisciplinary" (Takeuchi et al., 2020) to describe the links and integration of many disciplines. Several research studies have discussed the effectiveness of STEM through multidisciplinary integration (Nurtanto et al., 2020; Vasquez, 2015; Wang et al, 2020).

According to Drake and Burns (2004), multidisciplinary and cross-disciplinary are often used interchangeably. The authors explain that there are several different approaches to constructing a multidisciplinary curriculum, and they seem to vary in the degree of complexity.

A multidisciplinary curriculum is one in which the same subject is taught from multiple viewpoints or from different ideologies (Drake & Burns, 2004). Multidisciplinary integration is seen as a typical laboratory experience, according to Wang et al. (2020), in which teachers present the material to students. The authors explain that this model will establish informal conversations between students and teachers in other areas outside the classroom, and help teachers and students see how different STEM projects can create a shared laboratory experience. In the opinion of Wang et al., while the potential exists for greater collaboration between teachers and students through a multidisciplinary model, the model itself is not known as interdisciplinary learning. Therefore, a multidisciplinary model is characterised by the distinct instruction of subjects, with minimal integration or overlap between them (McComb & Jablokow, 2022). Conversely, an interdisciplinary promotes students' ability to establish links across different subjects, cultivating greater understanding of the content (Gao et al., 2020). Hence, although a multidisciplinary curriculum model recognises the presence of multiple disciplines, it does not actively strive to integrate them in a unified manner, thereby differentiating it from the interdisciplinary approach.

Interdisciplinarity is the practice of integrating two or more skills to solve a problem or clarify a procedure. In this sense, by using interdisciplinarity integration, students combine information or skills from two different fields (Gao et al., 2020). In accordance with this requirement, knowledge that is taught and learned follows the practices and formats of an existing and structured culture. Interdisciplinarity is discipline-based education and is beneficial in helping students gain knowledge and develop skills in specific fields, as it decreases the complexity of knowledge (Helmane & Briška, 2017). Additionally, interdisciplinarity is discipline-based education, where a student could gain information within an area in which they have experience.

A transdisciplinary approach to integration allows teachers to coordinate curricula around students' questions and concerns (Drake and Burns, 2004). Students acquire life skills by incorporating interdisciplinary skills and disciplinary skills in a real-life setting. The authors describe two directions leading to transdisciplinary incorporation. The first is project-based learning, where students address a real-world issue through their studies. Project-based learning is sometimes referred to as problem-based learning or place-based learning. Indeed, schools have also begun to introduce project-based learning lessons to help students become more actively involved in their learning (Gubacs, 2004). The second is curriculum negotiation. In this type of transdisciplinary approach, students' questions form the basis of the study material.

By definition, project-based learning implies that the two terms are often used interchangeably (LaForce et al., 2017). The hope is that presenting legitimate, real-world problems will draw the attention of students, and that their interest will be maintained by the stimulating and collaborative nature of the learning method.

Similarly, the Ignite Learning Model provides a framework to assist students in solving real-world problems using STEM strategies (Ignite, 2006). Ignite is a design thinking approach that tackles one sustainable development goal (SDG) at a time (United Nations, n.d.). This learning model was formulated with the intention of improving student learning, and to allow middle school students to learn in the most effective and efficient ways possible. The model was built on three fundamental beliefs (Ignite, 2006):

- All students have a talent for learning; they learn differently.
- Humans learn best by engaging in games, forming associations, and making use of concepts.
- Technology can be instrumental in motivating students to learn in a more productive and efficient manner.

Ignite was founded at Duke University but has since been administered by Fundegua Foundation in Guatemala (Dotson et al., 2020). Four integral segments in the Ignite Learning Model include:

- Empathy
- Design and brainstorming.
- Prototypes
- Field evaluation featuring feedback.

The model was intended to boost critical thinking skills, encourage problem-solving skills, and develop the technical expertise required to turn a sketch into a tangible prototype. In this way, students communicate directly with their peers and have a better understanding of the communal issues relevant to SDGs. It is also possible to facilitate community learning through STEM events, which can provide students with knowledge about the environment in which they live. During the ideate and prototype creation processes, students are to work in teams to develop concepts and use feedback to iterate their designs. Students will propose a matrix definition and seek input from their peers. During the presentation, panellists ask questions and provide supplementary feedback. Students display their prototypes at school and for special guests at places such as science fairs (Dotson et al., 2020).

Research by Kelley and Knowles (2016) suggests that teachers are unable to comprehend the interdependent nature of STEM subjects, leading to students becoming disengaged from science and math because of fragmented and isolated learning experiences. Consequently, students are unable to connect crosscutting concepts with practical applications due to an ineffective integration of both.

Margot and Kettler (2019) argue that it's necessary to understand the teaching beliefs and expectations of STEM talent growth to incorporate quality STEM education. Teachers hold previous views and experience that will affect their STEM instructional abilities. Integration is a key factor in deciding the inner balance of a school in such a way that the initially separate contents of independent school subjects are met and integrated in the educational phase (Helmane & Briška, 2017).

Several components are essential for STEM integration, according to the authors of a study on STEM integration (Sukarman & Retnawati, 2022). These components include teacher knowledge of STEM integration and pedagogical subject competency expertise. In this research, teachers were concerned about the costs associated with introducing STEM education to their classrooms. Additionally, teachers had to spend more time creating instructional materials. Teachers with extracurricular commitments found collaborative scheduling to be time-consuming and difficult. When STEM is integrated, concerns related to science, technology, engineering, and mathematics require an understanding of all four disciplines; subjects such as engineering and technology education emphasize the importance of understanding science and mathematics curricula and their application. In this regard, teachers should possess a deep understanding of these topics.

Sukarman & Retnawati (2022) found that teachers' insufficient knowledge regarding the implementation of interdisciplinary STEM education impedes their effectiveness. Furthermore, a lack of understanding of the STEM integration framework has a negative impact on the delivery of STEM training in educational settings (Sukarman & Retnawati, 2022). The challenges associated with STEM integration were also discussed by Diana, et al. (2021), who discovered that Indonesian mathematics teachers had no prior experience teaching STEM subjects, making it difficult to find real-world challenges that relate to their mathematics courses. Teachers were forced to employ a STEM-based approach to mathematics instruction due to inadequate learning tools and materials. Teachers also experienced increased time constraints and were unable to engage with STEM professionals and specialists.

As outlined above, research into integration of multiple STEM disciplines remains limited and provides insufficient guidance for STEM advancement (English, 2016). Additional research is needed to determine how incorporating different STEM principles impacts student learning outcomes.

### 2.2.2. STEM in the curriculum and schools

The integration of teaching is characterised as the organisation of teachable subjects that have not previously been taught in one academic course or department, and for them to be interrelated or unified (Joglekar et al., 1994). To satisfy the need for more STEM graduates, both elementary and secondary schools are integrating STEM-based curricula and pedagogies into their schools (Margot & Kettler, 2019). Despite this, it can be challenging to contextualise science, technology, engineering, and mathematics into practical applications.

As far as STEM curriculum is concerned, Bagiati and Evangelou (2015) found that teachers face many integration obstacles. For instance, teachers are concerned with implementing the curricular designs of others. Teachers are also constrained by uncertainty when it comes to curriculum flexibility. Le et al. (2021), meanwhile, found that teachers have concern about the lack of standardised curricula, materials, and teaching models suitable for teaching STEM subjects, as students received fundamental knowledge within specific domains, while materials and equipment are geared toward other areas, thereby failing to promote interdisciplinary learning. In addition, teachers encountered challenges in identifying STEM concepts for the curriculum and lacked the necessary guidance for integrating STEM into the classroom.

Given these challenges, what is the process of disciplinary integration in schools?

Curriculum integration refers to the process of connecting different subject areas or disciplines to create a more holistic learning environment for students. This approach recognises that subjects are interconnected, and that learning can be more meaningful and effective when students explore topics from multiple perspectives.

One-way disciplinary integration can happen through interdisciplinary projects. This is where students work on a project that combines different subject areas, such as science and art, to create a more comprehensive understanding of a topic. Another approach is team teaching, where two or more teachers from different subject areas collaborate to plan and deliver lessons that integrate their respective disciplines. Thematic units are also a common way to integrate disciplines, where a particular theme, such as sustainability or social justice, is explored across different subjects. These approaches help students develop critical thinking skills and promote a deeper understanding of the world around them.

### 2.2.3. Assessment in STEM

Although attempts have been made to incorporate STEM subjects into curriculum, assessment-related issues remain a challenge (Margot & Kettler, 2019). With the current paradigm of discipline-based education currently prevalent in most educational systems, there are several concerns regarding how STEM education can be assessed and evaluated in an interdisciplinary manner. Students' interdisciplinary understanding has been difficult to assess, and integrated instruction has not been adequately evaluated (Herro et al., 2017). Science, technology, engineering, and mathematics are comprised of the primary STEM disciplines and their subfields, such as physics and geometry (Gao et al., 2020).

According to the *White House Report* (2022), STEM assessment should be aligned with the trajectory of transdisciplinary teaching, learning, and evaluation at the convergence of education. The report makes the point that transdisciplinary is neither the only nor the most effective strategy, but that it can be used in conjunction with all levels of integration, including disciplinarity, multidisciplinary, and interdisciplinarity, all of which have their own unique values, needs, and roles. Additionally, the report suggests incorporating flexibility in convergence education so that desired outcomes can be achieved, including:

- In a discipline-based approach, concepts and abilities will be addressed independently, enabling students to interact with and be evaluated in the context of a single discipline.
- Multidisciplinary approaches involve sharing a topic or method for students to connect concepts and skills taught in different disciplines. Diverse disciplines are not interconnected.

- Transdisciplinary approaches require students to identify and solve complex problems, develop shared conceptual frameworks collaboratively, and integrate cross-disciplinary ideas, concepts, and activities. The interconnected nature of the world, the significance of societal issues, and the involvement of students have helped learners develop a more substantive understanding of real-world topics. In contrast, a transdisciplinary approach integrates a wide range of disciplines in a distinctive manner that promotes genuine and meaningful learning experiences. Through this approach, students are empowered to drive innovation by being provided with substantial opportunities to engage with student-centred challenges based on their own descriptions (White House, 2022).

In their study, Le et al. (2021) discussed assessment. A lack of direction provided by school leadership hampered teachers' ability to assess students' STEM achievement in their research. Traditionally used methods of assessing student knowledge, such as paper-based examinations, were not sufficient to assess students' progress in STEM-related courses. There was an understanding among teachers that the outcomes and procedures of STEM activities should be reviewed. Further, teachers expressed concern about the perception of fairness in group assignments and individual tests by their students.

### 2.2.4. STEM and teacher training

STEM curriculum adoption has encountered obstacles due to insufficient teacher training (Diana et al., 2021). During the implementation of STEM curriculum, Madani (2020) emphasised the importance of teachers receiving appropriate training. A lack of subject knowledge of STEM topics has been identified as a factor attributed to inadequate training (Margot & Kettler, 2019). Pelger's (2022) research found that teacher training plays a critical role in facilitating the successful implementation of STEM curricula, while Al Salami et al. (2017) discuss insufficient teacher training for STEM adaptation. Meanwhile, Bagiati & Evangelou (2015) found that educators are aware of the importance of integrating STEM concepts into their teaching practices but aren't confident in their ability to apply these concepts effectively in the classroom. However, professional development training offers significant benefits for educators who specialise in science, technology, engineering, and mathematics. Zhou et al. (2023) note that STEM professional development activities can be categorised as engineering-based, inquiry-based, problem-based, project-based, or integrated STEM activities. Teachers are impacted by these activities in terms of their knowledge and practice. Teachers can enhance their understanding of STEM disciplines by engaging in these activities. In Gok's (2022) research, interviewed teachers expressed challenges in integrating STEM education into their teaching practices, specifically within mathematics and computer science.

### 2.2.5. STEM gender stereotyping

Hussain et al. (2015) define gender stereotyping as sociology, which categorises individuals based on specific characteristics such as gender, age, ethnicity, nationality, language, and religion. Stereotyping, according to sociological discourse, involves preconceived judgments based on unfounded generalisations of individuals. Gender stereotyping, therefore, pertains to societal norms dictating how men and women should conform to their roles in society.

Parents, unfortunately, perpetuate gender stereotypes intentionally or unintentionally. Albert Bandura's Social Learning Theory explains that parents serve as models of gender roles for their children based on their attitudes, professions, and preferences, which influence their children's behaviour (McLeod, 2016). Studies have shown that parents often treat boys and girls differently (Barcellos et al., 2016), and girls, for instance, may imitate their mother's caretaking role rather than aspire to professional expectations, if their mothers are not in paid employment.

Bian et al. (2017) aimed to determine when girls become aware of gender stereotyping. This was done by examining a sample of children from different age groups, including those between five and seven years old. The children were given certain tasks from a story; one was to identify the protagonist. The children were given a selection of two male and two female characters. Another group of children in the study were given a puzzle consisting of objects that represented hardware tools. A third experiment included sample participants deciding which of the two genders they perceived to be more intelligent. The authors found that children in this age group were unaware of gender stereotyping, and that girls were more likely to select the female character in the given tasks as being more intelligent, while the boys followed a similar trend but with respect to their own gender. The sample of children in the age group of between six and seven years old, however, produced different results. Here the girls would identify male characters as being more intelligent. In addition to this, with regards to the given tasks performed by the children, girls would shy away from proclaiming themselves to be more intelligent despite their superior performances.

There is a significant gender imbalance in STEM courses and careers because of gender stereotyping, resulting in an underrepresentation of females in STEM fields at both the school and university levels. Recognising bias in STEM disciplines is crucial to addressing this issue (McGuire et al., 2020). In addition, the negatively biased assessments of women in STEM careers may lead to more women leaving the STEM career field, or the decrease in their self-esteem, and them subsequently beginning to doubt their own ability to perform adequately in their occupations (Alzaabi et al., 2021).

The relationship between STEM and gender stereotyping has been explored in several studies (McGuire, et al., 2020; McKinnon & O'Connell, 2020; Riegle-Crumb et al., 2017). For instance, Riegle-Crumb et al (2017) found that gender stereotyping is prevalent in classrooms when a STEM subject is being taught by a male teacher. As a result, an abundance of male STEM teachers can enforce the notion that science, technology, engineering, and mathematics are predominately male professions. Further, the authors noted that there were insufficient numbers of women in

STEM occupations. The authors thus attempted to find out whether males' and females' "stereotypical viewpoints" could be changed if they were taught engineering by a female teacher, and if more female students were present in the classroom.

This study was designed to raise awareness of the low participation of women in STEM fields, particularly in fields such as engineering, where their representation is particularly low. Researchers have primarily centred their attention on identifying what is deterring women from these fields, what challenges they may be encountering, and consequently try to help them overcome these hurdles. The authors found that males became less stereotypical when the class was led by a female teacher, suggesting that a primary mechanism for minimizing stereotypical attitudes of male students could be to ensure a strong presence of females in classrooms either as peers or as educators.

It is evident that gender biases concerning who is more likely to succeed in STEM fields can have long-term effects on students' interest in STEM subjects, and gender assumptions associated with STEM can significantly impact later STEM careers engagement (McGuire et al., 2020). Gender stereotyping undermines female career choices in STEM and may explain why women who initially pursue STEM occupations eventually leave their chosen field.

Ertl et al. (2017) investigated how gender stereotyping affects female university students' self-concept. The authors also sought to identify the challenges women who successfully entered STEM fields had to overcome to combat gender stereotypes. The study sample was comprised of 296 female students taking STEM courses. The findings indicated that female students had a positive self-concept, but the authors contend that this was likely due to the students already being enrolled in male-dominated STEM courses. Participants reported that their parents were supportive of their choice of subjects, but the authors indicate that one of the female participants revealed that her father had expressed his doubts about her abilities to succeed in the STEM field.

Math gender stereotyping can negatively influence girls' understanding and performance in mathematics if they grow up believing that they have inherently inferior mathematical capabilities than males. Cvencek et al. (2011) used a self-report questionnaire that compared American children against other nationalities to evaluate children's mathematics-related gender assumptions and math self-concepts during primary school years. The study revealed that girls displayed a lower propensity toward mathematics than boys in both tacit and self-reported tests (the math self-concept). This suggests that mathematics-related gender assumptions may develop at a young age, and that such discrepancies are only detected between boys' and girls' self-identifications with mathematics when an assessment of mathematics achievement arises.

Parents may be contributing to the issue of gender stereotyping in STEM subjects (Henschel et al, 2023). The role of the mother and her assumptions regarding mathematics, and whether these sorts of factors influence how a young Latin American learners perceived mathematics, was the focus of work by Denner et al. (2018). Their research sought to improve understanding of why Latin American children were shown to be underperforming in mathematics. They found that higher rates of maternal mathematics gender expectations predict a greater decrease in mathematics involvement. For this reason, the authors' findings indicated that Latin American mothers' interests in mathematical dominance contributes to mothers showing less interest in helping their daughters with mathematics at home. The authors further argue that mothers are more prone to refrain from assisting their daughters in mathematics-related work because they feel that mathematics is not as important for girls, due to their beliefs that girls don't have as high an aptitude for mathematics as boys.

In another research study that investigated whether mothers had a role in fostering the mathematics gender gap, Tomasetto et al. (2011) proposed that parents' assumptions regarding possible gender disparities with regards to aptitude for certain fields of study may have increased their children's susceptibility to the threat of gender stereotyping. The authors' findings were consistent with the abovementioned studies, in suggesting that gender stereotyping will affect girls' ability to succeed at mathematics. Additionally, a finding from this study suggests that math stereotyping only occurs among mothers who perceive mathematics as a subject more suitable for boys.

Del Río et al. (2021) aimed to assess the phenomenon of math stereotyping in a sample of first-grade children in Chile, with a particular focus on the performance differences between young boys and girls. The study delved deeper into children's perception of mathematics and examined familial influences. The study investigated the underlying assumptions held by Chilean children; it examined the influence of parental attitudes toward mathematics and parental involvement in mathematics-related activities on children's attitudes prior to their formal education. Moreover, the study investigated whether males possess an innate advantage in mathematical proficiency compared to females. The findings of this research suggest that parents can consciously or unconsciously transmit gender stereotypes to their children with regards to their inclination toward mathematics. The study's findings indicated that male participants had higher comprehension levels of mathematical topics than their female counterparts. The research indicates that it's crucial to address gender stereotypes in mathematics throughout early childhood, along with promoting parental involvement, to foster positive attitudes toward mathematics across genders.

The foundation phase is the phase in which students first interact with mathematics, and it thus serves as the groundwork for the day-to-day use cases of mathematics. Unfortunately, many children – and even adults – don't feel comfortable when faced with mathematical problems. The inherent difficulty of mathematics can make us feel overwhelmed and nervous (Zhang et al., 2019). When children fear mathematics, they may begin to doubt their ability to prosper in the subject, and some may even subscribe to the idea of mathematics being too difficult to fully grasp. It is thus the unfortunate reality that many members of society – young and old – have developed a great disliking for the subject.

In the long run, this notion may foster poor mathematical skills in individuals throughout their school years, and even into their adult lives. Considering the significant negative consequences of mathematics-related anxiety, Wu et al. (2013) examined the effects of such anxiety on third-grade learners. The aim of the research was to determine whether mathematics-related anxiety had an influence on learning performance. The elementary students in the study ranged between seven and nine years of age. Even among students who were performing at or above grade level, there was a significant negative correlation between mathematics-related anxiety and mathematics ability. Mathematics-related anxiety was also detected in second-grade girls. For girls, the effect of mathematics-related anxiety was substantially higher than for boys (Van Mier et al., 2919). Mathematics-related anxiety appears to affect girls from a young age, and anxiety can persist and worsen as they progress through school.

Devine et al. (2012) conducted a study of 482 secondary school students, which supported the hypothesis that girls experience more mathematics-related anxiety than boys. Based on the findings, girls are clearly susceptible to developing mathematics anxiety. This study found that female students often suffer from this anxiety from elementary school through high school, resulting in a decline in their mathematical abilities. According to the authors, girls may be more proficient at mathematics than their male counterparts, but that girls' performance was negatively affected by their high levels of mathematical anxiety.

Gender stereotyping is also present in the discipline of physics. The assumptions present in this field may be attributed to a similar stereotype that exists in society regarding science being more suited for men (Kerkhoven et al., 2016). Physics does require a base of mathematical knowledge and thus, students who struggle with mathematics may potentially struggle with physics as well. These difficulties are likely to be manifested in the solving of equations and use of various formulae. To investigate how the complexity of physics may influence students, Ornek et al. (2008) recorded the perceptions of 1,400 students with regards to physics and its perceived difficulty. The students reported mathematics and lack of motivation as possible reasons why they found physics difficult (Ornek et al., 2007).

When female students struggle with physics, they will be far less likely to include any scientific disciplines among their subject choices at a high school or university level. This deduction was tested in a longitudinal study characterised by the analysis of data collected from 9,000 elementary school students and 170 interviews of parents and students (Archer et al., 2013). This study aimed to determine the prevalence of science disciplines in the career goals of girls. It was discovered that most of the participants believed that science is controlled by men. The results were determined based on the comments provided by parents throughout the interviews.

In their research, Gudyanga and Kurup (2017) focused on physics underrepresentation among female students in Zimbabwe. The authors highlighted that cultural and societal factors play a significant role in shaping young girls' aspirations. African cultures usually dominate the household, and women are expected to manage household chores. This societal expectation may discourage young African females from pursuing disciplines that are viewed as more suitable for men.

To understand the influence of identity as a contributing factor in the pursuit of physics as a career, the authors employed a qualitative method that used narratives to give female Zimbabwean students the ability to discuss factors that may encourage, or discourage, them to take physics. The study concluded that there is a need for female physics teachers, especially those of African descent, as they may serve as role models for younger African females to help develop the confidence and motivation needed to pursue careers in physics. Furthermore, the participants mentioned that male teachers don't have as much patience with female learners in classrooms. It will thus be beneficial for female learners to receive more encouragement in classrooms. In addition, the female learners in the study highlighted parental beliefs about the perceived "masculinity" of physics. The authors also noted that most female participants in the study shared similar responses regarding physics (Gudyanga & Kurup, 2017).

Kessels and Hannover (2008) also explored the masculinity of physics, arguing that, to overcome the masculine stigma associated with the subject, it may be beneficial for female students to attend single-gender classes. The authors suggested, through their research, that female learners in single sex classes would have a higher self-concept in physics and would thus perform better in the subject then female learners in mixed classrooms. The authors arrived at their conclusion after attempting to investigate the benefits of single-sex classrooms, derived from discussions on means of increasing female engagement in the field of physics. Despite the findings, the authors revealed that bias was present in the research findings, due to the students in the study having been split between mixed-sex classrooms and single-sex classrooms, as well as teachers' interferences possibly occurring (Kessels & Hannover, 2008).

Most of the studies discussed in the above literature review have centred on students. However, the perception students have regarding their lecturers may also contribute to gender bias. One example of this work is a study that examined physics students' perceptions of video-recorded presentations by female and male professors (Graves et al., 2017). The authors used male and female actors to play the roles of physics professors. A sample of 121 male and female participants was drawn, and data was collected using an open-ended response questionnaire. The study found that male students had biased views of male professors, with male professors generally receiving more positive ratings from male students.

In contrast, female students rated female professors' interpersonal/communicative skills more favourably than male professors. However, female professors' scientific knowledge and skills were evaluated less positively than their male counterparts, similar to how male students rated them. These findings highlight the challenges students face when studying STEM subjects. Research has shown that young girls already experience difficulties with mathematics in the early stages of their education. As they progress to high school, physics becomes particularly challenging for female learners, which may be related to their struggles with mathematics. Furthermore, mathematics and physics are often perceived as male-dominated subjects, which needs to change to ensure women are not excluded. To achieve this, there must be more female role models in educational centres that promote STEM education in their classrooms.

## 2.3. Summary

The UAE has recognised the importance of STEM education in preparing its students for the challenges of the future, and has set ambitious goals to promote STEM learning at all levels of education. The UAE Vision for 2018 aimed to create a knowledge-based economy driven by innovation, and STEM education was seen as a crucial component of achieving this goal. However, there are several challenges that remain to STEM education integration in the UAE, including enhancing teacher training and professional development, providing more opportunities for hands-on learning, and promoting the participation of girls and women in STEM fields. The solution to these challenges will require concerted efforts from policymakers, educators, and the community to ensure that all students have access to high-quality STEM education and have the skills and knowledge necessary to succeed in 21st-century jobs.

# CHAPTER 3.
# STEM PROJECT-BASED LEARNING AND CRITICAL THINKING SKILLS

Using STEM in education requires a distinct teaching methodology to address the challenges previously discussed. The application of constructivist theory can provide a helpful framework. The implementation of this theory, however, requires the use of specific and tailored methodologies. It is one such methodology that facilitates the integration of STEM into the classroom and fosters the development of critical thinking skills among students. The purpose of this chapter is to explore the constructivist theory that serves as the foundation of this research, and to introduce the concept of STEM project-based learning and critical thinking skills development.

## 3.1. Constructivist theory

The constructivist approach is based on the philosophical ideas of Immanuel Kant and the psychological theories of Jean Piaget (Dennick, 2016) and Lev Vygotsky (Vasileva & Balyasnikova, 2019). The philosophy of learning has gained traction in recent years in social science research, as Dennick (2016) points out, and constructivism encompasses both the philosophy of learning and the philosophy of information. A constructivist perspective in social science refers to a set of principles regarding the nature of the world and how we understand it. Additionally, this perspective offers different approaches to studying human phenomena that are aligned with these principles (Dennick, 2016). Specifically, constructivism makes an important contribution to action research, in that it acknowledges that individuals "construct" meaning through their experiences (Nada & Shapiro, 2007).

Depending on the author's perspective and position, constructivism can have different meanings. It has been found that social and educational constructivism has had a positive impact on the development of curricula and teaching practices (Terwel, 2019), and has contributed to the integration of current approaches to teaching and learning. The theory of constructivism is not a theory of teaching, but rather a theory of learning and knowledge (Bodner, 1986). Constructivism has had a significant impact on education in several published curricula (Dennick, 2016; Jones & Brader-Araje, 2002) and in instructional practices; it defines learning as an active process based on students' preconceptions and prior knowledge (Anthony, 1996; Cooperstein & Kocevar-Weidinger, 2004).

The constructivist theory focuses on knowledge creation and the use of cognitive activities to develop critical thinking skills in a scientific environment (Akpinar et al., 2009). Constructivism describes the knowledge transmitted, or discovered, by the humans engaged in making meaning (Novak, 1993) in the communities of social discourse (Durrheim, 1997) and cultural discourse (Cobern, 1993). Hence, constructivism is considered the theory of cognition, teaching, personal knowledge, educational ethics, and learning. Constructivism also drives initial scientific and mathematical exploration (Wheatley, 1991).

The key elements of constructivist education include experiential (Mughal & Zafar, 2011), analytical (Dennick, 2016), and self-directed (Sze-yenga & Hussain, 2010) learning. Creating ideas is central to science education, leading to a collaborative process that puts learners at the centre of knowledge-creation. Through constructivism, students can analyse meaning critically in the classroom (Topolovčan & Matijević, 2017), which empowers students to develop knowledge and skills.

Developed in the early 1920s, constructivism is based on the work of developmental psychologist and biologist Jean Piaget, who specialised in child development (Sjøberg, 2010). Piaget exemplified that people create new knowledge through the methods of integration and adaptation in their everyday encounters. According to Piaget's theory, children explore their environment and develop an understanding of the world that is akin to scientists' (Reynolds & Sherrell, 2021). Through cognitive processes of assimilation and adaptation, they create mental models that change and evolve as they encounter new experiences. Lev Vygotsky also observed that children become more aware of their environment as they grow and develop (Huang, 2021). Piaget's work can also shed light on students' critical thinking skills in the 21st century, according to Jumaat et al. (2017), who use the constructivist approach to integrate Piaget's contributions to education. In Piaget's theory, learning is a personal process in which individuals construct their understanding of the world for themselves. As a result, a person's perception of the world continues to evolve as they gain more knowledge.

### 3.2. Piaget's Constructivism theory

Piaget's theory focuses on concepts relating to development and learning (Jumaat et al., 2017). Development focuses on the learner's ability, and learning focuses on the achievement of these skills (Piaget, 1964). Piaget advocated active engagement in learning to enhance learning experiences (Bond, 2012). When children use mechanisms to play and explore things around them, their cognitive ability improves. Piaget's constructivism includes learning theories, methods of teaching, and reform of education. One of the core factors of Piaget's theory is assimilating, a concept relating to what causes a person to integrate new experiences into old experiences (Hanfstingl et al., 2021). When individuals are exposed to this phenomenon, they gain new perspectives, correct previous misconceptions, identify pertinent information, and ultimately become more open-minded.

Piaget's constructivism philosophy emphasises the process of learning, not the driving forces behind it. Rather than lecturing, teachers serve as facilitators, guiding students to develop their own understanding (Murphy, 2018). Piaget's understanding of how students learn allowed him to identify four primary stages of cognitive development (Awwad, 2013). According to Piaget, all children progress through these stages on their way to higher levels of cognitive development. Each stage explores new intellectual abilities and a greater understanding of the world. While the ages at which children progress through these stages may vary based on their context and life experiences, children often exhibit traits associated with more than one stage at a time (McLeod, 2018).

A key feature of Piaget's theory is the idea that learning is the result of knowledge being acquired through experience. This enables cognitive development and learning to be incorporated into contemporary educational systems (Piaget, 1964). Throughout the development stages, Piaget sees learning as an active process that benefits from the knowledge students have gained by building on their preconceptions (Bond, 2012). The stages are as follows:

### Sensorimotor stage

In Piaget's theory, the first stage is the sensorimotor stage, which begins at birth and lasts for approximately 18 months to two years. In this stage, children navigate their environment primarily through physical movements rather than symbols. Initially, they are only aware of the sensations and experiences they encounter on a physical level. As they cannot yet predict the outcome of their actions, they learn through trial and error. The experiment Piaget conducted to test whether a child will search for a toy hidden under a blanket was designed to assess the development of "object permanence." It has been found that children typically acquire the ability to mentally represent objects in their minds between eight and 12 months of life (Mcleod, 2018).

### Preoperational stage

In the preoperational stage, a person is between 18-24 months and early childhood (7 years). At that time, children begin using language; memory and creativity also begin to develop. In the preoperative stage, children engage in believing and can understand, and articulate relationships between past and future. During the preoperational stage, the child portrays the following characteristics (Mcleod, 2018): centration, egocentrism, play, symbolic representation, and pretend or symbolic play. Centration means that children have difficulty concentrating on multiple tasks, which is regarded as normal in the early stages of childhood. In fact, children may have difficulty with decentring in social circumstances, as often as they do in non-social circumstances (Mcleod, 2018). Although centration displays basic mistakes in logic, it could also demonstrate the transition from intuitive problem-solving to true logical reasoning, that is learned as the child grows up. Egocentrism is the period of development marked by self-consciousness and lack of distinction between the ego, the alter ego, and the universe (Kesselring & Müller, 2011). In the common use of the word, an egocentric person is an arrogant individual who is concerned with his/her own self-importance. However, there is a difference between the egocentricity of a child, and that of an adult. For example, Kalyan-Masih (1973) explains that a child is self-centred because he/she cannot accept another's point of view, whereas an adult is self-centred because he/she merely refuses to. As a child develops, egocentrism refers to the child's inability to perceive a situation from the perspective of another individual. Consequently, egocentric children assume that other children perceive the world similarly to themselves, including seeing, hearing, and sounding similarly to them (Kesselring & Müller, 2011).

Play during the preoperational stage shows that the child has not yet developed social skills. They would for example, play in a room with other children; but will play alone and are self-absorbed with their own feelings and emotions (Mcleod, 2018). While playing, a child still learns and develops their cognitive abilities (Ahmad et al., 2016). Furthermore, the child is learning to navigate social interactions with others, manage feelings, and control their own behaviour (Fisher, 2001). As Fisher notes, play provides children with valuable opportunities to develop their ability to solve problems and make decisions. The development of these skills is crucial to the cognitive development of a child, and play plays a significant role in the growth of a child's creative abilities.

Additionally, Ahmad et al. (2016) argue that the expansion of creativity is linked to cognitive growth, because creativity results in problem solving. Through play, children potentially learn how to communicate with others, build dialect aptitudes, learn how to problem solve, and may discover their full potential with these new developments in their cognitive growth. As a result, children can gain a more thorough understanding of their position and role in society through play. Furthermore, the authors assert that a child's cognitive abilities tend to increase significantly during the structured operational stage of development. Nevertheless, it should be noted that children of the same age may not necessarily have the same level of cognitive ability.

A symbolic representation is a mental representation that is primarily based on the external characteristics of the acquired object or phenomenon rather than its content or its similarities to other objects or phenomena in the mind (Mcleod, 2018; Veraksa & Veraksa, 2015). In children, symbolic representation is a mode of perception that is reflected in their behaviour. It's an important aspect of child psychology and is frequently observed during children's play, particularly during imaginative or pretend play, a long-standing subject of interest in developmental psychology.

### Pretend or symbolic play

Piaget's theory offers valuable insights into children's developmental processes and highlights the significance of symbolic play as a crucial element of a child's cognitive and social maturation. Symbolic play serves as an effective tool for children to comprehend the world they inhabit and form mental representations of it (Fein, 1979). According to Petrović-Sočo (2014), in symbolic play, a child solves individual or complex problems, without fear or acting. This process introduces and adjusts various behaviours, putting them in new and unique situations where he/she uses common patterns and assesses them. The child then adjusts them accordingly. The author further explains that symbolic play reflects realistic, explorative, strategic, and functional play in child development. Thus, children perceive play as mental exercise. For instance, a child raises the question of why to exercise the action of posing questions, and repeats vocalisations, instead of seeking an answer. Furthermore, symbolic play provides children with the ability to acquire meaning, which assists them in communicating by making use of expressions, intonations, objects, and words replacement as abstract symbols.

### Concrete-operational thinking stage

The next developmental stage, the concrete-operational thinking stage, characterises an essential part of cognitive development. This stage usually develops between 7 and 11 years of age and is marked by exceptional cognitive growth. As children's capacity for logical thinking expands, their language skills and acquisition of fundamental abilities also improve. Cognitive advancement at this stage is characterised by the orderly and rational use of symbols linked to concrete objects (McLeod, 2024). This phase emphasises the logical progression of cognitive development, which encompasses concepts such as "conservation, reversibility, and reasoning." These mental activities are typically limited to real-world scenarios and are difficult to replicate in hypothetical situations. To examine concrete operational theory, various activities that embody concrete operational principles are employed (Börnert-Ringleb & Wilbert, 2018).

### Formal operation stage

The last developmental stage is the formal operation stage, which coincides with the transition from puberty to adulthood. McLeod (2010) suggests that adolescents and adults use abstract symbols. The process involves considering multiple variables, formulating theories, and contemplating abstract relationships and concepts. At this stage, Piaget identified six key thinking skills: conceptualising balance, abstraction of ideas, deductive logic, abstract reasoning, problem-solving, and hypothetical-deductive reasoning. These are explained below:

### Conceptualising balance

Piaget used balance to explain physical cognition. An age-diverse group of children was instructed to balance a scale. The formal operational stage involved 13-year-olds hypothesising where the weights should be placed to achieve balance. As opposed to the 10-year-olds who used trial and error, the seven-year-olds simply placed the weights on either side of the scale without taking any consideration of their positioning.

### Abstraction of ideas

The second task asked students to consider where they would position a third eye if they could. While young children tend to place the third eye in the middle of their forehead as a more conventional placement, children at the formal operational stage offered more innovative solutions, such as repositioning the eye behind the head to observe what is happening behind them (Lynch, 2021).

### Deductive logic

A deductive reasoning approach involves combining more than one generally accepted premise to reach a conclusion (Jeon et al., 2020). Inductive interference is unique for several reasons, and this type of inference can be used to judge necessity (Piaget, 1986). Two factors contribute to the infinite nature of hypothetico-deductive processes and co-necessities that Piaget observed. Both valid and invalid hypotheses can be used to draw appropriate conclusions. Additionally, the subject gains the capability to develop operations after implementing initial operations, thereby acquiring increasingly robust requirements over time as the subject continues to implement operations. Moreover, the concept of continuous change binds one state to another, which further explains the limitless possibilities available at this third stage. According to Piaget, this supports the idea of an indefinite number of characters. Individuals are capable of drawing appropriate conclusions from hypotheses that have been deemed valid as well as hypotheses that have been deemed incorrect. A further advantage of this is that individuals can perform operations as soon as they begin working and therefore develop increasingly robust needs (Piaget, 1986).

### Abstract thought

During the formal operational stage, a child's ability to think abstractly is developed. During the early stages of a child's development, they tend to think in a concrete and specific manner. It is imperative for children to learn to consider possible outcomes and repercussions of their actions rather than relying solely on their past experiences when making decisions (Cherry, 2022).

### Problem-solving

A key aspect of Piaget's theory was the investigation of children's performance both in pairs and on an individual basis during a pre-defined task (Cherry, 2022). Findings indicate that children who work with another child who is more advanced are more capable of solving problems than children who work alone (Fawcett, 2005; Tudge et al., 1996).

### Hypothetical-deductive reasoning

Piaget suggests that "hypothetical-deductive reasoning" is crucial during this stage of cognitive development. It is during this stage of development that adolescents are capable of abstract and hypothetical thoughts (Cherry, 2023).

## 3.3. Connecting Piaget's constructivism to project-based learning

The observations Jean Piaget made throughout his life led to influential models of cognitive development and learning (Watt, 1989). Models such as these have informed project-based learning (PBL), an instructional approach based on constructivism, and transformed modern-day teaching by providing insights into how children develop (Ojose, 2008). When children grow physically and intellectually, he or she links new information to a network or schemes of pre-existing knowledge. Development of a child is affected by how he/she understands and reacts to physical interactions in the world. As the child grows, these structures become more complex.

LEGO developer Seymour Papert, a supporter of Jean Piaget's theories, asserts that Piaget was among the first theorists of cognitive development to propose an ontological realism in which knowledge is evaluated impartially. Papert (n.d.) argues that Piaget's theory is unique in that it focuses on how children acquire knowledge.

In his constructivist theory, Piaget emphasised the importance of hands-on experience, one of the principles of project-based learning. The stages of development represent significant milestones in their discovery process, culminating in the formal operational stage, where higher-order skills are applied to real-life problems. Children are referred to as "little scientists" (Cherry, 2022). Piaget's theoretical model of cognitive development suggests that individuals are capable of abstract reasoning at the formal operational stage, which typically begins at age 11 (Piaget, 1964). In PBL, students can acquire and refine these higher order thinking skills, which can help develop and refine their cognitive abilities. As part of the formal operational stage, students can clarify and evaluate the various components of a problem, thus improving their ability to decipher the specific details that will be required to resolve an issue by enabling students to derive relevant knowledge from a problem statement (Ojose, 2008). According to the author, using inference in the formal operational stage, students can apply logical reasoning to existing knowledge to form a conclusion. Brainstorming is one of the most important activities in PBL (Bender, 2012), as it enables the student to generate ideas during the research process. The correlation between the formal operational stage and the PBL stage is the student's use of logic and reasoning to understand a concept (Jalinus et al., 2017).

Ojose (2008) suggests employing specific parameters to determine the validity and dependability of a proposed solution during the formal operational phase. It's possible to form hypotheses with precise outcomes using this procedure. Students apply a method of gathering evidence and making conclusions to address real-life issues during the PBL phase (Jalinus et al., 2017). An application stage is defined as the ability to apply existing knowledge to new knowledge and find a solution to a problem (Ojose, 2008). During the PBL stage, students demonstrate their ability to solve problems and present their findings to their peers (Jalinus et al., 2017). The formal operational stage shows that young adults can evaluate situations objectively in terms of causal relationships. This process involves the utilisation of higher order cognitive abilities to examine hypothetical situations and contemplate potential questions that may emerge in the future. Piaget's demonstration of the formal operational stage highlights the necessity for children to progress through all stages of cognitive development to devise solutions that were previously beyond their cognitive capacity.

### 3.4. Origins of project-based learning (PBL) and its relationship with STEM

A project-based learning approach incorporates constructivism, which focus on learning by doing. McMaster University in Canada was the first university to implement PBL as a common practice in medical education (Neville & Norman, 2007).

According to Capraro et al. (2013), PBL is an instructional methodology that provides realistic experiences (Paredes & Vázquez, 2019) that are vital for students to construct unique scientific, technological, engineering, and mathematical ideas. Furthermore, PBL improves learning experiences (Rofieq et al., 2019) and empowers students to become adept STEM practitioners (Chistyakov et al., 2023). Consequently, PBL is used by educators as a suitable instructional methodology and has been introduced into STEM classrooms (Han, 2017).

In PBL, students are typically presented with a broad inquiry prompt, a concrete problem to understand, or a complex issue to investigate (Sahin, 2013). Teachers may encourage students to identify specific topics that pique their interest or align with their career aspirations or personal passions. PBL is an instructional methodology that places the student at the centre of the learning process. It uses an active exploration of real-world problems and challenges students to deepen their understanding of the subject matter (Ozier, 2017). This approach provides opportunities for immersive learning experiences, as well as the development of critical skills relevant to both academic and professional contexts (Buck Institute for Education, n.d.). STEM PBL has proven effective in enhancing students' knowledge of science, technology, engineering, and mathematics.

Several studies have demonstrated the effectiveness of PBL as a STEM teaching method (Bicer et al., 2015; Ruamcharoen et al., 2021; Sarwi et al., 2021). PBL and STEM education are also closely associated. Sarwi et al. (2021) demonstrated that STEM-integrated project-based learning improved students' problem-solving abilities. Furthermore, PBL has been incorporated into STEM education as a means of enhancing course content (Ruamcharoen et al., 2021).

PBL is supported by several studies asserting it is an effective method of teaching STEM subjects. Moreover, the studies included in this current research have pointed out that critical thinking skills are among the skills that students develop when PBL is integrated into a STEM curriculum. According to research by Rochim et al. (2021), conventional learning methods are the primary factor affecting students' learning outcomes. PBL models built into STEM are effective in improving these outcomes. As a result, the authors argue that STEM-integrated PBL can improve students' ability to achieve the first learning outcomes at school in a sustainable and synergistic manner. Additionally, Sarwi et al. (2021) advocate integrating PBL into STEM education. It is essential for inclusive STEM schools to follow the PBL approach (Noble et al., 2020). PBL is a powerful pedagogical tool for integrating STEM, according to Navy and Kaya (2020), as it prepares students for the real world, teaches them that failure is not bad, and that STEM lays the foundation for future success. Furthermore, Rasul et al. (2016) discovered that PBL in STEM education could enhance students' 21st -century skills by providing real-life experience to solve real-world problems. The results of another study consistently showed that PBL models that are integrated into STEM subjects improve the learning outcomes in science, physics, and mathematics (Rochim et al., 2021). PBL is also shown to be effective in science education by Markula and Aksela (2022). Additionally, LaForce et al. (2017) noted that PBL has the potential to increase student STEM attitudes and interest.

STEM not only highlights its support in science, technology, engineering, and mathematics; it also exhibits an all-encompassing strategy for the provision of guidance in the improvement of student performance (Kazu & Yalcin, 2021). Furthermore, it enhances information cognition and perspectives required for fruitful critical thinking and advancement in the present economy. STEM project-based learning requires more than just learning content and applying it in the classroom; it involves flipping the methods of teaching and learning to achieve optimal content acquisition (Eichler, 2022). This is possible through a task-based learning methodology. Students are first given a real-life problem and afterward gain proficiency in addressing the problem. During the process of attempting to solve the problem (research, ideation, and creating arrangements), students engage in critical thinking and other aptitudes essential to solving problems inside, and outside, the classroom (Parno et al., 2021).

Research in STEM project-based learning in the UAE is currently limited. Although there have been some published studies, most focus on assessing critical thinking of students independently rather than as part of a STEM PBL approach. Most of the research on STEM PBL in the UAE is sourced from the British University in Dubai. For example, one master's thesis by Abdallah (2017) explored the deployment of STEM projects in a school in the UAE, using STEM indicators such as group formation, differentiation, achievement, motivation, assessment, and gender differences. Similarly, another student from the same university, El Sayary (2014), examined STEM PBL's influence on cognitive, collaborative, and content knowledge. Additionally, most of the STEM education research is authored by Sufian Forawi, a staff member at the British University in Dubai (2024), where most of the STEM PBL thesis research has been conducted. This dearth of research diversity suggests a lack of evidence for the effectiveness of teaching STEM subjects using approaches aimed at developing critical thinking skills, or their integration in vocational secondary education in the UAE.

While Jang (2016) discussed the general benefits of STEM PBL in the UAE, no significant research has been done to measure the actual effectiveness of STEM education in developing critical thinking skills. However, research exploring the impact of STEM PBL on students' 21st century-relevant thinking skills found visible improvements (Fouad, 2018). Additionally, the study found that students' knowledge of science, technology, engineering, and mathematics had increased. Students perceived STEM PBL positively.

A STEM project-based learning approach is necessary to integrate into vocational secondary education. The effectiveness of STEM project-based learning methods in nurturing critical thinking abilities and enhancing academic performance must be evaluated. STEM project-based learning has gained popularity in several schools and universities in the UAE, including Al Ibdaa Model School and Omar Bin Al Khattab Model School, in the UAE (Edarabia, 2015). Many professionals, educators, and parents in the UAE believe that STEM education offers foundational knowledge, making it essential for career building. Furthermore, STEM education is also widely prevalent in other GCC and Arabic countries, where it is closely aligned with their national agendas and visions. Current data indicates a highly positive outlook for STEM project-based learning in the Middle East, particularly in the UAE, where the government recognises its importance in achieving their National Goals (UAE, 2022). By incorporating STEM education, the UAE can enhance engineering and applied sciences education, promote innovation, and achieve national objectives. Given the importance of STEM education for ensuring future economic sustainability, it is reasonable to anticipate that the UAE will thrive in this field. Furthermore, an increasing number of graduates pursuing STEM careers can significantly contribute to the UAE's progress towards achieving its goals (Almurshidi, 2019).

### 3.5. Critical thinking

The advancement of critical thinking skills remains a greatly discussed topic (Lloyd & Bahr, 2010; Setyowati et al., 2018) as research has shown that Generation Z students fail to develop critical thinking in traditional classroom environments (Francis & Hoefel, 2018; Mapesos, 2017). Zhao et al. (2016) found that the best way to teach critical thinking is to expose students to creative and flexible learning environments. As Zapalska et al. (2018) point out, critical thinking is defined differently in different research studies. As defined by Dwyer and Rainbolt (2012), critical thinking is the ability to analyse arguments and present a compelling case in real-life situations, based on the capacity to make rational judgments. According to Brookfield (2012), critical thinking doesn't develop automatically without instruction or study, and cannot be acquired solely through reading texts, taking exams, or listening to teachers.

A critical thinking process involves reflecting on a problem and deciding what to believe or do based on the results (Ennis, 2013). Considering the preceding concept, Ennis views critical thinking not only as a decision about what one should believe or think, but also as an appropriate course of action. It has been suggested by Moreno (2015) that critical thinking skills should be taught in conjunction with mathematics instruction. In Moreno's view, conceptual teaching is an effective method for cultivating critical thinking skills in students. Students can apply these skills to mathematics and other STEM and social science fields (Moser & Chen, 2016). Based on Moser and Chen's suggestion, comprehension skills are crucial for students and will be of benefit to them throughout their professional careers. In addition, they assert that the ability to transfer skills and knowledge is more advantageous than simply transferring data, as the latter may become obsolete over time.

Radulović and Stančić (2017) define critical thinking as a cognitivist, rationalistic, individualistic, and decontextualised approach to teaching. This approach focuses on developing critical thinking skills through special educational programmes and methods. The authors argue, however, that alternative approaches to critical thinking education are possible, focusing on the understanding of the nature and purpose of critical thinking. Radulović and Stančić suggest that educational institutions should place a high priority on the development and teaching of critical thinking skills. They recommend that educators explore alternative methods for teaching critical thinking, including defining critical thinking, clarifying its purpose and benefits, setting educational objectives, describing techniques for enhancing critical thinking, and identifying strategies for integrating critical thinking into the classroom, among other strategies. Moreover, they assert that critical thinking skills alone cannot bring about transformative changes in teaching methods and the introduction of specialised programmes. Their argument is that it is imperative to challenge and reconstruct the status, roles, and power dynamics of both students and teachers in the educational process and curriculum development. As the authors further recognise, education can enhance critical thinking, but several factors can impede progress, including a lack of educator knowledge and commitment, a lack of training for prospective teachers, and systemic issues within the educational system. The authors emphasise the importance of not only equipping teachers with specific programmes, strategies, and techniques for developing critical thinking skills, but also inspiring them to gain a thorough understanding of curricula and the distribution of power in education as part of teacher preparation and training. In this broader perspective, teachers are empowered to effectively implement critical thinking education in the classroom.

The stages that go into the progressive development of critical thinking skills are explained by a number of theories that have been created in the fields of cognitive development and education. Both Bloom's Taxonomy and Elder and Paul's six stages of critical thinking offer important insights into how individuals evaluate information, solve problems, and draw logical conclusions. This section primarily focuses on Bloom's Taxonomy and Elder and Paul's critical thinking models since they provide a framework for comprehending critical thinking and its significance in education. Below is a discussion of both:

### 3.5.1 Bloom's Taxonomy model

Bloom's Taxonomy is a popular model for teaching pupils critical thinking (Adams, 2015; Rahman, 2017). Bloom's Taxonomy is based on a classification system, widely discussed in educational research (Adams, 2015; Hyder & Bhamani, 2016). According to Adams (2015), knowledge, comprehension, application, analysis, synthesis, and evaluation comprise the six stages of taxonomy.

*Knowledge*

Krathwohl (2002) explains that the knowledge group represents both noun, and verb, elements of the original taxonomy. The noun, or subject, aspect was defined in the extensive knowledge subcategories. The verb aspect was included in the knowledge description, as the student was required to remember or understand facts. Regardless of whether a student has significant prior knowledge of the topic or not, questions at the knowledge level of Bloom's Taxonomy are designed to encourage students to provide information. As described by Adams (2015), this level involves questions regarding dates, events, and who, what, when, where, and why.

*Comprehension*

The comprehension level of Bloom's Taxonomy has students move past the basic reviewing of realities and encourages them to comprehend the data. Students can employ a variety of methods to understand the information they encounter including rephrasing it in their own words, categorising items into groups, comparing, and contrasting similar entities, or explaining what they have learned to others. At this level, they will gain the ability to decipher realistic problems. Students engage with cognisance-based questions once they can interpret commands such as "describe, discuss, contrast, predict, or paraphrase" (Adams, 2015).

*Application*

Application-based questions teach students how to apply the information they have learned. Students are asked to respond to questions that instruct them to "complete, solve, examine, illustrate, or show" (Hyder & Bhamani, 2016).

*Analysis*

Analysis is the class where the skills seen as critical thinking starts to emerge. The differentiation between facts and opinions and the definition of the arguments on which the statement is based involve research, as well as the breakdown of the need for evidence into its components.

*Synthesis*

With synthesis, students are required to utilise the provided real-world based scenarios to formulate innovative solutions (Adams, 2015). They may need to draw from information spanning numerous subjects and extrapolate from this information before reaching a conclusion. In the curriculum, students will be taught how to answer synthesis questions and comprehend key terms such as "invent, envision, create, compose" and other similar terms.

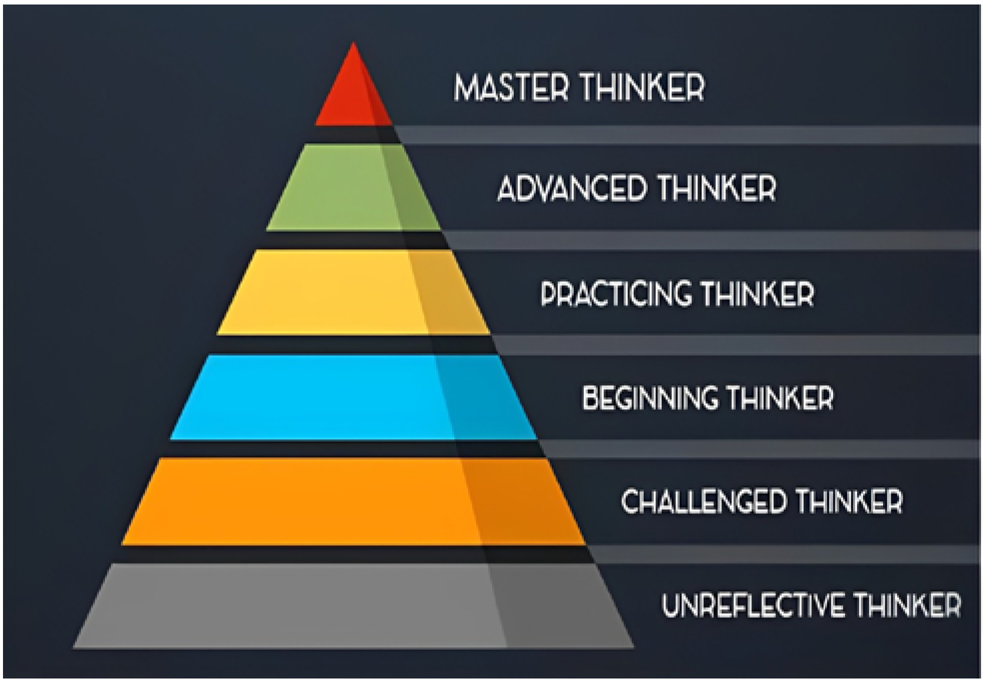
*Evaluation*

At the top of Bloom's Taxonomy is evaluation. Here students are relied upon to evaluate data to come up with a conclusion. Instructions in these questions include words such as "select, judge, debate, recommend" (Adams, 2015). Taxonomy has two features. First, using taxonomy allows teachers to think about learning objectives and understand what the student will do, as a result of the teaching. Second, when considering Bloom's taxonomy as a basis for learning objectives, it is necessary to incorporate goals that require higher-order cognitive skills, facilitate deeper learning, and facilitate the transfer of knowledge and skills to various tasks and contexts (Adams, 2015).

### 3.5.2. Elder and Paul critical thinking stages

According to Elder and Paul (n.d.), critical thinking development must progress through various stages. The transition from one stage to the next requires people to cultivate their critical thinking skills; critical thinking cannot be subconscious. Furthermore, the quality of student learning is closely related to the effectiveness of instruction, and there is a potential for regression in the development of critical thinking. Elder and Paul add that critical thinking development can be divided into six stages (Figure 2).

**Figure 2.** *Critical thinking pyramid*




**Source:** Elder/Paul, *How to think effectively: Six stages of critical thinking.*

*Stage one: Unreflective thinker*

Unreflective thinkers are oblivious of the impact that thinking has on their lives or the various ways that thinking problems contribute to their difficulties (Elder & Paul, 2010). An unreflective thinker lacks the ability to consciously evaluate his or her current thoughts and make the necessary adjustments. Unreflective thinkers are unaware of the importance of practicing and refining their thinking skills for the purpose of accomplishing high order thinking. Moreover, they fail to acknowledge that thinking involves concepts, assumptions, inferences, implications, and multiple points of view. Due to a lack of self-monitoring and self-awareness, unreflective thinkers have difficulty acquiring critical thinking skills. Thus, biases and misunderstandings frequently impair the quality of their reasoning.

*Stage two: Challenged thinker*

The transition to a challenged thinker is characterised by the realisation that thinking has a significant role in one's life and the fact that a lack of thinking is causing serious problems in their lives (Elder & Paul, 2010). According to the authors', challenged thinkers are aware of their flaws in their thinking, but are not able to identify them. It is also suggested that challenged thinkers may gain an initial understanding of thinking, which encompasses concepts, assumptions, inferences, implications, and perspectives. The authors discovered by examining the development of critical thinking that the flaws in critical thinking among challenged thinkers may be attributed to the belief that their thinking has progressed, making it difficult for them to recognise that poor thinking has inherent problems.

*Stage three: Beginning thinker*

Elder and Paul (2010) found that the beginning thinker recognises that they possess fundamental issues in their thinking. This suggests that the beginning thinker initiates efforts to understand how his or her critical thinking abilities can be altered and enhanced. Moreover, the authors note that although beginning thinkers may modify certain aspects of their thinking, they remain unaware of the underlying complexities of their thinking. In this stage, critical thinking occurs when the beginning thinker accepts criticism of their abilities and begins to identify instances of egocentric thinking in themselves and in others.

*Stage four: Practicing thinker*

Those who engage in critical thinking are aware of the significance of developing certain practices, to effectively manage their thought processes (Elder & Paul, 2010). Not only do they recognise that there are flaws in their reasoning, but they also recognise that these issues must be addressed comprehensively and systematically. Recognising the significance of regular practise, they evaluate their thinking in a variety of domains on a regular basis. In spite of this, since these practising thinkers are still in the early phases of systematically enhancing their thought processes, their comprehension of profound levels of thought and the complexities underlying them is limited.

*Stage five: Advanced thinker*

Critical thinking is engrained in the daily routines of advanced thinkers (Elder & Paul, 2010). Although advanced thinkers can think effectively in significant domains, they don't yet demonstrate high-level thinking development. During this stage, advanced thinkers actively and successfully monitor the influence of concepts, assumptions, inferences, implications, and points of view on their thinking, thereby gaining a comprehensive understanding of the topic. In addition, they recognise the significance of routinely assessing the clarity, accuracy, precision, relevance, and logical understanding that underlie their reasoning. In addition to comprehending egocentrism and sociocentrism in thinking, they also comprehend the relationship between thoughts, emotions, and desires.

*Stage six: Master thinker*

According to Elder and Paul (2010), master thinkers are continuously examining, modifying, and reassessing their strategies to strengthen their critical thinking abilities. The authors elucidate that master thinkers have profoundly internalised fundamental thinking skills, making critical thinking a conscious and profoundly intuitive process. In the authors' view, master thinkers are capable of routinely and effectively evaluating their own thinking methods. It is at this point that a master thinker can identify their critical thinking strengths and weaknesses.

As with Elder and Paul (2010), Greenlaw and Deloach (2003) have made an important contribution to the understanding of critical thinking stages. Specifically, Greenlaw and Deloach have developed a scale to assess critical thinking skills among students. Their scale presented the level of competence demonstrated by students as they engaged in the complex task of constructing arguments. By engaging in this process, students can develop their abilities according to the complexity of the perspectives they encounter. The scale is composed of a number of arguments. In progressing through these levels of critical thinking, student gradually transitions from the fundamental cognitive phases of learning and understanding (levels 1 and 2) to the more sophisticated cognitive phases of applying and analysing (level 3). Ultimately, the process reaches its apex in the realm of critical thinking, wherein pupils skilfully amalgamate and assess information, attaining stages 4 through 6. Providing teachers with a comprehensive framework to cultivate and evaluate students' critical thinking abilities at various cognitive levels is one of the main benefits of Greenlaw and Deloach's (2003) model.

## 3.6. **Critical thinking and STEM PBL**

In several studies, critical thinking has been linked to STEM PBL (Eja et al., 2020; Oyewo et al., 2022; Rahmawati et al., 2021). As part of their research, Eja et al. (2020) assessed students' ability to think critically within a STEM project-based learning environment and found that STEM PBL promotes a high level of critical thinking through its process of contemplation, inquiry, discovery, application, and communication. Less is known about how children acquire critical thinking skills. Melo-Leon (2015) attempted to explore the acquisition of critical thinking skills in young children by observing and interviewing 98 preschool children aged six to eight. The author found that young children display critical thinking development through curiosity, questioning, and by actively participating in debates.

In research conducted by Oyewo et al. (2022), students developed innovative products through active exploration of PBL water treatment activities, which improved their critical thinking skills. Based on the authors' findings, PBL activities enhance students' critical thinking abilities, and STEM PBL can assist students in explaining concepts in a simple manner (Rahmawati et al., 2021). Further, Mabrurah (2023) research determined that 66 percent of students improved their critical thinking skills through STEM PBL, whereas Rogovaya et al. (2019) found that critical thinking is an integral component of problem-solving in STEM fields, and skills in critical thinking are crucial for effective problem-solving.

With its significant impact on human development, Piaget's insight in the formal operational stage is closely linked to critical thinking skills (Keating, 1975). Another follower of Piaget's theory is Supratman (2013), who refers to Piaget's research as "revolutionary." The author explained that Piaget's cognitive development focused on logical development. By combining logical operations and classifications according to accepted criteria, convergence of thinking occurs. Piaget himself explains critical thinking by clarifying that the application of knowledge to make sense of an object evolves in a form of transformation and is perceived because of the object under construction (Unveren & Karakus, 2020). As Piaget observed children when developing his cognitive development theory, Melo León (2015) emulated Piaget's research to advance his own research concerning the development of critical thinking in pre-schoolers. Children during their preschool years are curious and eager to learn about everything.

Critical thinking stages are beneficial in PBL, and the skills development process outlined by Elder and Paul (2010) is particularly important, as students engage in real-life problems that require complex problem-solving and decision-making. Students can assess the validity and reliability of information sources, identify biases, and evaluate the quality of evidence through critical thinking stages. This ensures that project work is supported by sound logic and evidence. In addition, Elder and Paul's stages of critical thinking facilitate the development of metacognitive skills in PBL, whereby students are able to monitor their learning progress and reflect on their own thought processes. The importance of metacognition during PBL cannot be overstated, as students actively participate in planning, implementing, and evaluating their projects.

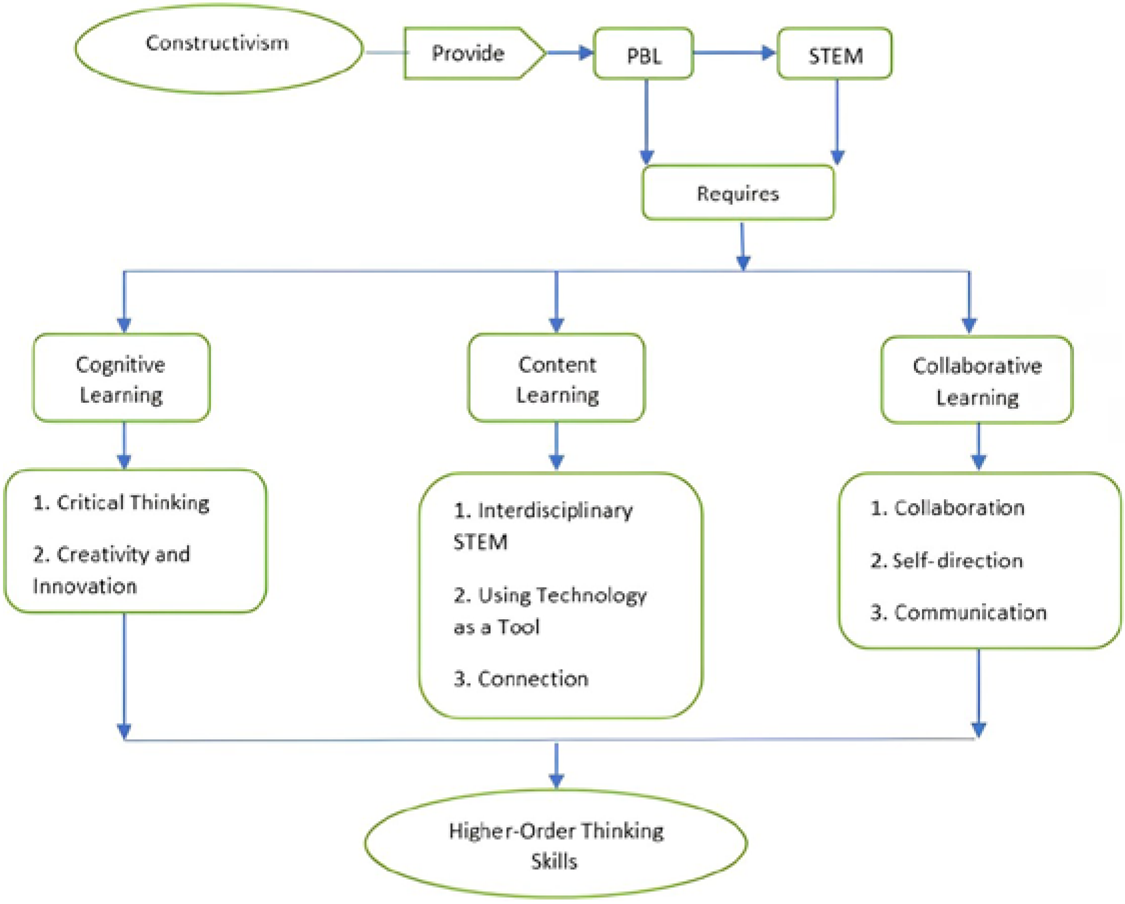
## 3.7. Summary

This chapter presented the theoretical groundwork for the research that follows, particularly with regards to critical thinking and its relationship with project-based learning (PBL) and STEM education. Evidence was presented on how PBL and STEM can be integrated with modern teaching strategies for students to experience a more engaging and interactive learning experience. The chapter discussed constructivism theory and its relevance to STEM education, and how STEM and PBL work together to create a more effective learning environment. In tandem, these two methodologies can help students develop a deeper understanding of concepts and build practical skills vital to success in the 21st century.

By integrating STEM into technical careers and using project-based learning methods, vocational education can be made more appealing to students. Project-based learning emphasises real-world problem-solving, collaboration, and critical thinking skills, and is a practical and engaging approach to learning. Despite this, there is a gap in research regarding the implementation of STEM project-based learning and the development of critical thinking skills among vocational education students. This chapter addressed this research gap by exploring how STEM project-based learning enhances students' professional competencies and critical thinking abilities.

- The visual mapping in Figure 3 shows how the constructivist approach relates to STEM education and project-based learning (PBL).

Figure 3. *Visual mapping*




Source: *Own elaboration.*

# SECTION II

## Research Goals

### CHAPTER 4.
### RESEARCH FOUNDATION, PURPOSE, AND OBJECTIVES

This chapter will examine the recent emphasis on vocational education and how the United Arab Emirates is playing an important role in equipping its citizens with the necessary skills to secure future employment. In response to a shortage of skilled professionals, expatriates have been hired in large numbers to fill vacant positions. A failure to address this phenomenon may lead to an increase in youth unemployment in the UAE and other GCC countries. To address this problem, more students must be attracted to vocational studies, and studies must be designed to enhance students' professional competencies as well as employing teaching and learning methods that will stimulate their interest in such studies. The integration of STEM into technical careers and the implementation of Project-Based Learning methodologies can therefore be effective strategies for achieving this goal. In this chapter, we explain the rationale for the research and highlight the existing research gap in STEM project-based learning and critical thinking skills development among students.

#### 4.1. Research setting

The research on STEM project-based learning and critical thinking skills development among students was conducted at a vocational high school situated in Umm Al Quwain, one of the seven Emirates in the United Arab Emirates. The school has separate campuses for boys and girls. Students in grades 9 through 12 are admitted to the school. This school enrols approximately 800 students, ages 13 to 18, who are primarily taught in English. This diverse educational setting provided an ideal context for investigating the effectiveness of Project-Based Learning in STEM subjects and its impact on fostering critical thinking skills among students. It was possible to gain insights into STEM education, PBL, and critical thinking development by conducting this research in a vocational high school within the dynamic educational landscape of the UAE.

## 4.2. Problem statement

Over the past decade, STEM education has attracted significant attention, particularly when combined with effective teaching strategies to prepare students for STEM careers, including science, technology, engineering, and mathematics (McCabe et al., 2020). It has been suggested by several studies that project-based learning (PBL) may be an effective method of teaching STEM subjects (Archer et al., 2013; Mosier et al., 2016). STEM PBL is, however relatively new in the UAE, and there has been little research that measures its effectiveness in improving students' mathematical performance, developing their critical thinking skills, and integrating it into high schools.

At present, only two schools in the UAE use STEM project-based learning – Al Ibdaa Model School and Omar Bin Al Khattab Model School, UAE (Edarabia, 2015). Although there is a growing consensus among professionals, educators, and parents in the UAE that STEM education provides foundational knowledge and is crucial to attaining a successful career, uptake of the dual curriculum model has not been widespread. Nonetheless, there appears to be a promising future for STEM PBL in the Middle East, particularly the UAE (John & Varghese, 2018). Despite this, research regarding its effectiveness in developing critical thinking skills among students is limited. If STEM project-based learning teaching procedures for vocational secondary schools were developed, it would be possible to monitor the effectiveness of STEM education in educating students. Researchers could also measure the effectiveness of this approach at developing critical thinking skills in vocational secondary education institutions.

## 4.3. Importance of this research

This research underpins the effectiveness of STEM project-based learning in promoting critical thinking skills among students. Teachers can use this information to better understand the number of factors that contribute to successful outcomes and make informed decisions to ensure that their students develop the skills and qualities they need. Furthermore, the study's insights may assist professionals in identifying weaknesses and addressing shortcomings of STEM project-based learning. By doing so, they may be able to improve the outcomes and effectiveness of this learning method, which will ultimately result in better educational outcomes for students. By shedding light on the effectiveness of STEM project-based learning, practitioners can contribute to the ongoing effort to improve education quality and ensure that students are equipped with the skills and competencies necessary to succeed in the 21$^{st\ century.}$

## 3.4. Aim of this research

This research aims to demonstrate that project-based learning (PBL) enhances students' interest in STEM subjects. It also seeks to evaluate the effectiveness of PBL in improving students' critical thinking skills. To achieve these objectives, two studies – one quantitative and the other qualitative – are discussed.

## 4.5. Objectives

The objectives of this research are as follows:

1. To determine how project-based learning (PBL) affects students' interest in STEM subjects (Study 1).

2. To examine the impact of PBL instruction in STEM on the development of students' critical thinking skills by considering changes in their critical thinking skills before and after PBL intervention (Study 1).

3. To recognise that PBL can create effective learning for students in STEM disciplines from the perspective of teachers and students (Study 2).

## 4.6. Hypotheses and research questions

In response to the first study, the following hypotheses are formulated:

1. The STEM interest of students who receive project-based learning (PBL) intervention will statistically differ from students who receive traditional instruction, with students receiving PBL intervention expected to be significantly more interested in STEM subjects. (Study 1).

2. We will find statistically significant differences in the critical thinking skills of students receiving project-based learning (PBL) instruction in STEM compared to students receiving traditional instruction in STEM. (Study 1).

To answer Study 2 posed in this thesis, the following research question is formulated: How can project-based learning (PBL) promote effective learning?

# SECTION III
## METHODOLOGY

### CHAPTER 5.
### METHODOLOGY

In this chapter, we provide a comprehensive introduction to the philosophical foundations of this research, design, and its rationale. The chapter also provides an overview of the sampling process and the instruments used. A discussion of ethical considerations concludes the chapter. The specific data collection methods and sampling techniques and how they relate to both quantitative and qualitative studies are discussed in detail in Chapters 7 and 8.

#### 5.1. Philosophical foundations guiding the research

Creswell (2009) suggests that the first step in selecting an appropriate methodological approach is to define your research philosophy. Rehman and Alharthi (2016) explore that this involves critically examining one's perception of reality, identifying what can be learned from it, and determining how to acquire knowledge. The application of this framework is used to assess the methodological components of their research undertaking, including the choice of research procedures and the manner in which data is manipulated (Kivunja & Kuyini, 2017).

According to Žukauskas et al. (2018), the notions of ontology, epistemology, methodology and play a crucial role in shaping the notion of scientific inquiry. In this respect, Bryman (2012) argues that all philosophical notions should be examined due to their theoretical frameworks for investigating and understanding social processes. As quantitative and qualitative research differ in their advantages and disadvantages, the philosophical underpinnings are equally critical to understanding their value. Research should be guided by researchers' philosophical paradigms, assumptions about their contribution to research, and strategies chosen based on these assumptions (Creswell, 2009). Several research paradigms exist today, owing largely to human intellectual discoveries and divergent interpretations of the existence and meaning of various phenomena. The two dominant ideas, positivism and interpretivism, jointly dubbed the "basic research paradigms," have produced a plethora of alternative paradigms (Adom et al., 2016; Kivunja & Kuyini, 2017). Among these are critical theory (Intgrty, 2016), social constructivism, and postmodernism (Rotaru et al., 2010).

The quantitative research paradigm defines positivism as the concept of using scientific evidence as a basis for understanding reality (Antwi & Hamza, 2015; Park et al., 2020). A qualitative paradigm, on the other hand, views reality as a product of human creativity (Erlingsson & Brysiewicz, 2013; Tubey et al., 2015). According to Creswell (2009), positivist assumptions are more appropriate for quantitative research. A positivist approach develops testable hypotheses (Park et al., 2020). Additionally, the authors describe positivism as logical and focused on identifying and influencing variables. In the authors' view, positivism implies the existence of a single, measurable reality. In the positivist perspective, there is a cause-and-effect relationship between occurrences, and once this correlation has been established, it can be predicted with confidence (Kivunja & Kuyini, 2017). Despite this, the authors contend that positivism is not an appropriate method for studying social phenomena.

Bryman (2012) describes interpretivism as an alternative to positivism in terms of epistemology. Interpretivism acknowledges that the subjective aspect of human behaviour has a lengthy history in social science (Chowdhury, 2014). The interpretivists are of the belief, as stated by Bryman (2012), that the social sciences are fundamentally distinct from the natural sciences in their focus on humans and their institutions. When investigating the social world, a methodological approach that considers the peculiarity of people in relation to the natural world is essential (Bryman, 2012).

Critical theory, social constructivism, and postmodernism are philosophical paradigms that are complementary to qualitative research since data relies on human constructs to explain reality. Critical theory can be applied to variables such as race, gender, or social class, for example (Asghar, 2013; Lötter, 2020).

In social constructivism, meaning is created through everyday social interactions (Boyland, 2019). Constructivism supplements a data collection technique that solicits feedback through open-ended questions (Adom et al., 2016). The ontological perspective of constructivism is that social realities and their interpretations are perpetually constructed by social actors (Creswell, 2009). It indicates that not only are social realities and categories formed through social interaction, but they are also continually revised (Bryman, 2012). It is the belief of social constructivists that individuals are constantly seeking to understand the world around them on both a personal and professional level (Creswell, 2009). Humans interpret these experiences subjectively, and the meaning of these experiences varies widely. To understand the phenomenon under study, researchers should seek a wide range of perspectives, relying heavily on participant perceptions rather than limiting meanings to a single category or concept. Participants often construct meaning from their experiences through discussion and interaction while answering open-ended questions. Using open-ended questions and paying close attention to their words and actions are essential to effectively capturing an individual's experiences.

With pragmatism the researcher can identify what is true and real about the phenomena under investigation at an ontological level (Polit & Beck, 2014). Pragmatism emerges from acts, contexts, and consequences (Creswell, 2009). According to pragmatists, human behaviour is inevitably shaped by the experiences and beliefs produced by the past (Kaushik & Walsh, 2019). As explained by the authors, human cognition and action are fundamentally intertwined. Considering their interdependence, individuals are encouraged to evaluate their actions and anticipate their future outcomes based on past experiences of similar actions. An individual with a pragmatic approach to research integrates both qualitative and quantitative methods, drawing on positivist and constructivist principles, as outlined by Creswell (2009). This author considers this approach as pragmatic, stating that the most appropriate research methods are those that are most effective in addressing the research question. The pragmatic approach to research stresses the importance of the way in which research is conducted, and how it is conducted. As Creswell (2009) explains, when incorporating qualitative and quantitative data, researchers must clarify the purpose of integrating the data and articulate their reasons for doing so.

It is argued by Bryman (2012) that empirical realism can be understood using appropriate procedures. Regardless of whether one is a realist or a positivist, there is no dispute that the social and natural sciences can and should use comparable methods for collecting and interpreting data. According to the author, there are two varieties of realism: empirical and critical. The principles of critical realism recognise the reality of social events and discourses as they are manifest in a natural setting. In critical realism, it is a central tenet that acknowledges both the actuality of the natural order and that of social events and discourses.

## 5.2. Paradigm for present research

This research adopts a pragmatic stance and combines qualitative and quantitative methodologies (Mitchell, 2018). As for the instruments, we assert that questionnaires are a common means of collecting data in quantitative research, and that they play a vital role in obtaining accurate and unambiguous information. Despite this, they fail to capture the "unwanted noise" in the survey process, such as comments on survey forms or explanations from participants as to why a form was not returned, which constitutes an important part of the research process and can compromise its credibility. A more comprehensive perspective can be gained by integrating qualitative and quantitative data, as respondents are able to elaborate on their responses when coupled with Likert scale questions. We have found that the pragmatic paradigm is better suited to comprehending critical thinking through hypothesis testing using questionnaires, and with interviews to complete the research process.

## 5.3. Research approach

Creswell (2014) explains that the research approach directs the research, and guides the researcher in formulating an appropriate research design, an appropriate data collection method, an appropriate data analysis method – as well as the presentation of the research, to apply to the area under study.

The two most frequently used research approaches are quantitative and qualitative, and the differences are underpinned in the way data is collected (Polit & Beck, 2014). Data collection methods are selected based on the type of data to be collected. Polit and Beck (2014) identify interviews, case studies, findings, and oral histories as qualitative research methods. On the other hand, quantitative research methods typically employ surveys, ordinal and nominal data, statistical analyses, and experiments, as outlined by Crookes and Davies (2004). Gunasekare (2015) suggests a mixed methods approach that integrates both quantitative and qualitative data within a single study. In the following section, we will provide a detailed description of each of these three primary research methods.

The use of quantitative research is common in both scientific and laboratory research (Bryman, 2012) in which data can be quantified. Quantitative research has been characterised by three historical developments, namely research design, testing, and measurement (Kabir, 2016). To ensure conformity with the method used for gathering statistical data, a method of inquiry is used (Williams, 2007). However, a frequent concern in quantitative research is the consistency of the results.

Rahman (2017) argues that qualitative research methods are not dependent upon quantifiable measures such as numbers, to arrive at conclusions. Qualitative analysis emphasises everyday realities such as personal experiences, social behaviour, emotions, and feelings. Comparatively to quantitative research, where human interference is minimized, qualitative research entails the researcher actively participating in understanding the participants (Creswell, 2009; Rahman, 2017). The qualitative approach aims to explain realism in the everyday world (Polit & Beck, 2014). Focus groups, participant observations, photographs, journal entries, and unstructured interviews have been used as methods of data collection (Trochim & Donnelly, 2008). This method relies on a convenient sample for the study setting and participant exploration (Creswell, 2009), and is more flexible than a quantitative methodology, allowing for data adjustment throughout the research process. It is important to note, however, that qualitative studies have some disadvantages, such as smaller samples, making it difficult to generalize findings from the research sample to the general population (Atieno, 2009).

The mixed research approach combines quantitative research techniques, including data gathering through surveys or experiments, and qualitative data gathering through interviews, focus groups, journals, observations, and personal narratives (Creswell, 2009; Harwell, 2011). However, before mixed methods became an acceptable research approach, so called "purists" considered only the quantitative research approach as empirical research (Olson et al., 2016).

Postpositivist and positivists engaged in a paradigm war in the 1980s regarding their worldviews (Bryman, 2012; Denzin, 2010). Positivism takes precedence in a quantitative approach to studying social phenomena (Majeed, 2019). Since the quantitative method is based on positivism, it exhibits distinct characteristics. As Park et al. (2020) point out, positivism places a strong emphasis on objectivity in research, which is defined as reducing biases and subjectivity throughout the data collection and analysis processes. It is the belief of positivists that social phenomena can be systematically explored by applying a scientific approach (Majeed, 2019). As opposed to positivists, post-positivists view the world from the perspective of scientific theory and rationalism (Maksimović & Evtimov, 2023). They argue that worldviews can be empirically examined (Tanlaka et al., 2019).

Mixed methods evolved because of this paradigm war, and Guba and Lincoln (2005) stated that they provided the optimal balance of positivist and post-positivist perspectives. However, the so-called "paradigm wars" sparked debates which continue to rage over the merits between quantitative and qualitative research. Followers of both approaches assume that their approach is better (Bryman, 2012). According to the author, the paradigm war centred around the "epistemological and ontological positions," of both approaches. Furthermore, Bryman (2008) views the paradigm war as being ungrounded, and more of a misunderstanding. According to the author, the clash stems from the presence or absence of quantification in interpretivism. In another study, Gunasekare (2013) discussed purists and the paradigm war, in which both parties agreed that quantitative and qualitative data should not be combined. The use of mixed methods, which incorporate both approaches, enhances research in comparison to using only one method.

Gunasekare (2015) suggests that using a mixed methods approach can enhance the reliability and validity of research. In this approach, triangulation is used to answer primary research questions by incorporating multiple perspectives through sequential mixing patterns (Johnson et al., 2007). The mixed methods approach emphasies structuring the research question (O' Cathain et al., 2007) to achieve this goal. The triangulation process combines several types of data within the theoretical framework applied to the data, while ensuring equal treatment for all data sets.

According to Creswell (2009), sequential explanatory design is one of the most popular mixed methods processes. Creswell argues that the popularity of the sequential explanatory design is that the findings of the results can be easily understood and written down. In a sequential explanatory design, quantitative data is collected and analysed first, followed by qualitative data. In Subedi (2016), it is emphasized that this approach is useful because it allows for a more comprehensive interpretation and qualitative analysis of the quantitative data. Although the initial results provide an overview of the research problem, further analysis - particularly through the collection of qualitative data - is necessary to further explore these findings. A primary focus on quantitative data is followed by a secondary focus on qualitative data in this approach.

In survey research, quantitative research methods, such as using questionnaires, can be combined with qualitative research methods, such as asking open-ended questions. Due to their frequent use in researching and describing human behaviour, surveys are commonly employed in social and psychological research (Ponto, 2015). It is argued by the author that the survey can be used to capture a wide range of information concerning research objectives, sampling strategies, recruitment strategies, data collection methods, and survey administration procedures. Survey research use independent and dependent variables to delineate the study's parameters (Christopher & Udoh, 2020). The authors assert that survey design is largely employed to depict, elucidate, and forecast the condition of certain phenomena and variables, as well as their interconnections, within a real-life context and across various age cohorts. The population exhibits heterogeneity.

In this doctoral thesis, a quantitative approach has been followed for Study 1 and a qualitative approach for Study 2. Chapters 7 and 8 will explain in depth the characteristics of each.

An intervention programme for STEM subjects based on problem-based learning is proposed. This intervention programme is explained in the following chapter.

# CHAPTER 6.
# PROJECT-BASED LEARNING (PBL) PLANNING PHASE

In this section, we will outline the steps involved in planning a 16-week course on STEM project-based learning. Moreover, it will explore how STEM project-based learning can be implemented in the classroom. As part of the next section, we will provide a detailed discussion of each phase involved in designing the intervention program.

## 6.1. Course framework design and plan

The 16-week course for the experimental group was designed with four parallel dimensions, operating simultaneously. The elements included:

1. School curriculum timeline
2. Students' main project timeline (snail car)
3. Interdisciplinary curriculum plan
4. Deming's cycle, PDCA Cycle (Plan, Do, Check, and Act)

Developing STEM PBL curriculum begins with a project plan. This stage involves conceptualising the project and identifying the teachers who will participate in the study. With the assistance of the school principal, we sent a formal request to the teachers to explain the concept of STEM PBL to them. The training was scheduled for the last week of August 2020, coinciding with the teachers' return from summer vacation. It's common for teachers to resume their duties a week earlier than the students while they still have one week of vacation left. The timing was ideal since Applied Technology High Schools normally organise professional development sessions for teachers during this week. Due to this, STEM PBL training became an integral part of their professional development programme. Two experts from the curriculum development team facilitated the training at the Umm Al Quwain Campus, UAE. Ten teachers attended the session, six from the science department specialising in physics, chemistry, and biology, and five from the engineering department. One week was devoted to training.

*Training objectives included:*

- An understanding of PBL in their subject area.
- The tools and activities of PBL.
- Assessment techniques for PBL.
- Ideas for motivating students to collaborate effectively.
- Using simulation activities and interactive projects to cultivate entrepreneurial attitudes in students and foster leadership abilities.
- Discussing obstacles and sharing best practices with their peers and trainers.

Each teacher received a certificate at the end of the training. Three teachers were identified as having implemented the most successful PBL activities during the study. The three teachers were awarded an extra day off as a reward, to be taken on the final day of the week prior to the break. Detailed information about the STEM PBL professional development training that was provided to teachers is mentioned in Table 1.

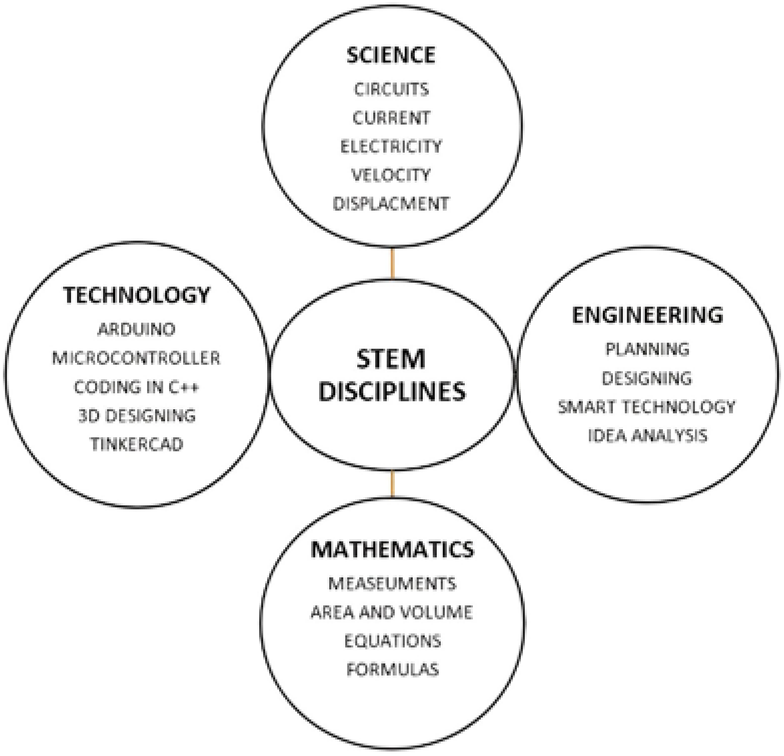
**Table 1.** *STEM PBL PD Training*

| CONTENTS | DESCRIPTION |
|---|---|
| **Introduction to STEM** | • Ability to develop a concept for STEM education.<br>• Increase their comprehension of the components of high-quality STEM / PBL lessons. |
| **Knowledge of engineering** | • Increase their knowledge of the engineering design process (EDP) and their degree of confidence to integrate problem-solving practices within their subject matter.<br>• Increase awareness of science and engineering practices. |
| **Connecting learning targets to real life problems** | • Ability to draft a standard aligned STM/PBL lesson.<br>• Development of a draft rubric based on learning goals.<br>• Ability to connect learning targets with real life problems |

## 6.2. Project idea and validating

This project is centred on integrating STEM curriculum (Figure 5) with practical applications in electrical engineering and mechanical engineering. This project involves the construction of a snail car prototype and exploration of a variety of applications, including controlling the speed of the vehicle using a mathematical approach (involving tire ratios, proportions, probability, and circumference); calculating the average speed of the car over a specified distance and time as a scientific application; constructing electrical circuits as an electrical engineering application; and using simulation programs as a technological application. As shown in Figure 4, students were assessed in specific areas within each of the four STEM disciplines.

Figure 4. *Interdisciplinary curriculum snail car project*




Source: *Own elaboration.*

With the idea formulated, three questions were presented as a way to validate the proposal:

1. Does the project have the potential to engage students?
2. Does the project engage teachers?
3. Does the project offer meaningful learning opportunities for the students?

To answer these questions, we reviewed the 11$^{th}$ grade engineering and science curriculum to ensure that the topics covered and utilised in the snail car's construction were included. Teachers recruited for this study were asked to validate their curriculum content to ensure that these subjects were incorporated into their lesson plans. We also asked the teachers if they believed the snail car would be a suitable STREAM project that would engage students and provide them with significant learning opportunities. The teachers confirmed that snail car can accomplish SMART objectives. With the snail car, students would have the opportunity to acquire hands-on training, constructivist learning would be emphasised, and a growth mindset would be fostered.

There were three criterions for compelling, essential questions to make the design of the snail car successful:

- It should be a question that is asked in the real world.
- There should be no easy answer to this question.

- Ideally, the question should ignite students' imaginations and enhance their ability to think critically.

Students were asked questions about the snail car they were going to construct to develop critical thinking skills prior to starting the current project.

- What is an input device? Explain why an input device is needed.
- What is an output device? Explain why an output device is needed.
- How can we control car speed?
- How can we control electrical current strength in a circuit?
- Which device in a car consumes the most power?
- Is there any way to save electrical power? Elaborate.
- How can the electrical power delivered to a load be maximised?
- Explain how a capacitor is charged (exponential growth).

A collaborative brainstorming session with the school's teachers was deemed essential prior to the beginning of this study, as it could enhance the success of both the study and the chosen project. To facilitate the exchange of best practices among teachers and gather feedback, the following topic was discussed: the degree to which this project complies with Adria Steinberg's six A's of project design (Steinberg, 1997). The aspects of this topic are further elaborated on below.

- What can be done to improve the project's connection to the community?
- Is there a possibility that the final output could be presented differently?
- Are there any organisations that may be interested (for example, universities or other schools)?

## 6.3. **Project Design**

As part of this process, we identified the project's objectives to design the project. This was to make sure that the project and the materials available to the students would be feasible for constructing the snail car. Furthermore, we contacted experts in the project's field of study, and we were able to complete the documentation including the project sheet, the project planner, the project's schedule, and the assessment criteria.

### 6.3.1. STEM PBL objectives for teachers

To ensure the development of critical thinking skills among students, it was imperative to engage them in the process of building the snail car. As such, participating teachers were provided with specific objectives related to science, technology, engineering, and mathematics, including:

- Teach the basic concepts of ratios.

- Teach proportions and equations with variables on both sides.

- Teach learners to be able to find the probability of simple events.
- Provide learners with instructions on how to determine the average speed of an object based on the distance it has travelled over a given period.
- Educate learners on how to calculate the circumference of a circle (the tire of a car).
- Explain that the circumference of a tire corresponds to the distance travelled by a car, since a tire's circumference correlates with one revolution of a wheel.
- Be able to demonstrate an understanding of the selection of electrical circuit components.

### 6.3.2. Objectives for students

After completing this project, students should be able to:

- Describe how the power delivered to a load can be maximised by applying knowledge gained from STEM subjects and specific electrical components, such as capacitors and inductors.
- Analyse motor behaviour using polynomials and use the results to build a control system for a car.
- The derivatives of functions can be used to change the frequency at which electrical switching occurs in a circuit, resulting in changes in output device speed.
- Calculate the rate of change in velocity for a car moving in one dimension by using acceleration vectors.

### 6.3.3. Contacting those with expertise in the field

At this stage, we consulted with experts in engineering science, engineering mathematics, electrical engineering, teaching, and learning to develop a meaningful task for the students in the sample. Some of the individuals consulted include:

- Eng. Karim Ragab, Principal of Applied Technology High school of Umm Al Quwain.
- Eng. Mohammed Abdou Applied Engineering Lead Teacher at Applied Technology High school of Umm Al Quwain.
- Amer Al Jarrah, Assistant Prof -ETS (math and physics) Faculty of Engineering at Higher Colleges of Technology. See Chapter 5, heading 5.7.2.

### 6.3.4. Documentation

All necessary documentation was completed during the documentation stage.

- Students received a sheet containing the essential project questions, project objectives, and timeline for their projects.
- The project planner includes an overview of the project, essential questions, an outline of what students should be doing, learning objectives, and a timeline with milestones.
- STEM project-based learning detailed timeline. This document provides information regarding the integration of STEM domains in each classroom.
- Criteria for assessing STEM project-based learning (project rubric).

## 6.4. Snail car key performance indicators expectations of students

The learning outcomes key performance indicators (KPIs) are the following:

- Calculate rations. Students had to consider factors such as size and weight of the snail car and desired speed.
- Solve proportions and equations with variables on both sides. Students had to use algebraic manipulations and pay attention to details. It was essential that the students understood the specific equation they were working with and applied the appropriate techniques.
- Find the probability of a simple event. Students were required to calculate that probability that the snail car would move a certain distance within a given period.
- Find the car's average speed, given the total distance covered by the car over time. The students were required to calculate how long it took the car to cover the distance and how much time it took to travel that distance.
- Find the circumference of a circle (car's tyre). Students had to use measurements.
- Understanding how a car's tyre circumference can be used to estimate distance travelled by the vehicle based on wheel revolutions. Students were asked to estimate the distance travelled by the vehicle.

## 6.5. Suggested procedures for designing a STEM project-based learning plan

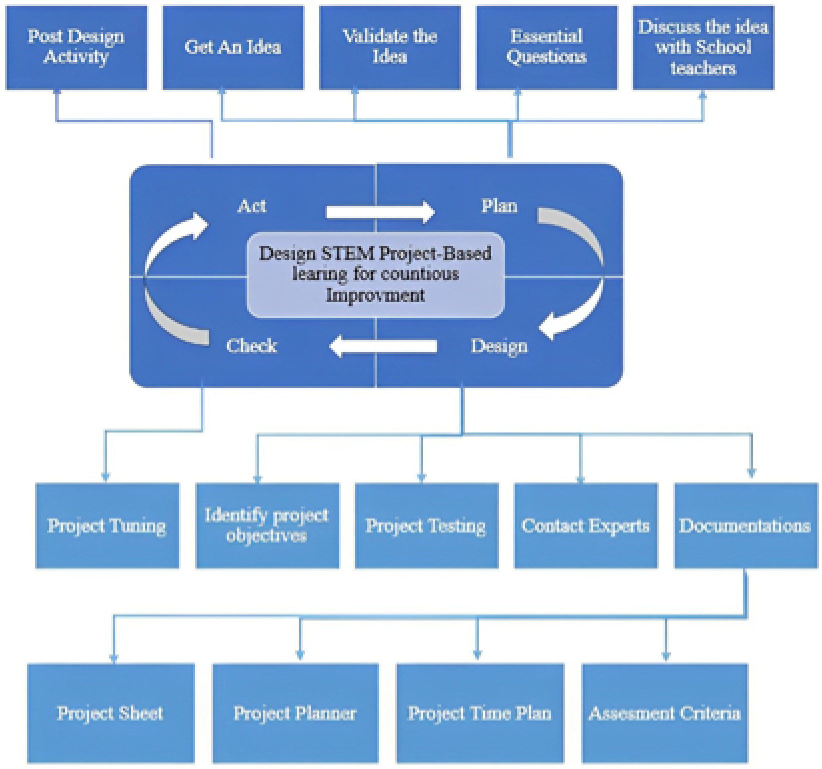
For enhancing the success of the snail car project, the Deming Cycle (Plan, Do, Check, Act) was introduced to students (Figure 6). Students had the opportunity to reflect on the knowledge and ways of thinking that are needed to solve problems in an innovative way. Moreover, the Deming Cycle provided teachers with an opportunity to assist students in testing solutions and assessing findings. Figure 5 illustrates how the Deming Cycle was applied in this study.

Deming's cycle represents the logical framework of the suggested procedures for designing a STEM project-based learning plan. The Deming Cycle is also known as the Deming Wheel, and is a model centred around enhancing the efficiency of an individual's personal learning (The W. Edwards Deming Institute, 2022). The cycle begins with the announcement of the "Plan" stage. This stage is characterised by the identification of an objective, the formulation of an action plan, and performance measures.

There are four essential phases that must occur in the PDCA cycle (MindTools, n.d.). This phase involves identifying learning outcomes and creating a roadmap outlining the steps necessary to achieve them. Upon completion of the Plan stage, the cycle continues to the "Do" stage, which consists of implementing the strategies outlined in the previous stage, carrying out the planned activities, and conducting experiments. Once the Do phase has been completed, the cycle enters the "Check" phase. This phase involves assessing progress toward the defined objectives and evaluating the results. Performance is evaluated and compared to the established performance measures. By completing this assessment, gaps or areas for improvement will be identified.

The final stage of the cycle, "Act," is initiated following the evaluation conducted during the Check phase. To enhance learning outcomes, an action plan may need to be adjusted, learning strategies adapted, or additional resources and support sought (The W. Edwards Deming Institute, 2022). It is important to note that the PDCA cycle (The W. Edwards Deming Institute (2022) is a continuous loop, with the completion of the Act phase leading back to the Plan phase. As a result of this iterative process, learners refine their learning approach, adapt to changing circumstances, and continuously improve their ability to learn. The Deming cycle is illustrated in Figure 5.

Figure 5. *Deming cycle*




Source: *Own elaboration.*

In Table 2, the Deming cycle stages are used in the snail car procedure.

Table 2. *Deming cycle stages – procedures used for construction of the snail car*

| DEMING'S CYCLE ELEMENTS | ACTIVITY |
|---|---|
| Plan | Project planning:<br>In this stage we attempted to conceptualise an idea for the project and then validate it by answering three main questions surrounding students' and teachers' engagement, as well as the meaning of the idea. If the idea is validated, the researcher then formulates the project's essential questions. Finally, we discussed the idea with the teachers selected for participation in the current study. |
| Design | Project designing:<br>Here the researcher designs the project, and thereafter consults experts in that field of study. The researcher then completes the necessary documentation, such as: the project sheet, the project planner, the project's time plan, and the assessment criteria. |
| Check | Project tuning:<br>In this step, we presented the plans to a group of schoolteachers specialising in math, science, and engineering to gather contractive feedback to identify other problems that may have not been anticipated. |
| Act | Post design activity:<br>Finally, the feedback from the tuning step is used to enhance the planning of the project. |

As part of this 16-week intervention, the PDCA Cycle (Table 8), a conceptual framework proposed by the The W. Edwards Deming Institute (2022), was used to plan and implement the intervention in a systematic and organised manner. PBL integration in STEM approach to construct the snail car.

The 16-week course encompassing science, technology, engineering, and mathematics was designed to achieve this goal. Students were instructed and made aware of current global trends, specifically those related to sustainability. The use of interdisciplinary teaching methods enabled students to combine knowledge from multiple academic disciplines and apply them to problem-solving, resulting in a comprehensive learning experience that fostered critical thinking and problem-solving abilities.

The experimental group was instructed on how to construct a snail car using project-based learning (PBL) methods, while the control group was instructed using traditional learning methods. The teacher assumes an authoritative role in traditional teaching methods, restricting the opportunities for students to interact with the teacher. PBL, on the other hand, entails the teacher facilitating the learning process as well as encouraging student input, feedback, and ideas in the classroom. In PBL classrooms, students and teachers are encouraged to participate in active discussions. It took 10 weeks to construct the snail car.

Students were provided with guidelines on how to complete the task using two different educational strategies, PBL and traditional. Due to the study being conducted during the new academic year of 2020-2021, and with the uncertainty of the COVID-19 pandemic's outcomes in terms of education in the UAE, we wanted as little interference with the classroom instruction and pacing. This project was supported by the director of Applied Technology High Schools, the principals of the campuses in Umm Al Quwain and Dubai, as well as participating teachers and students. The prototype construction and interviews took place twice per week during the second lunch break, under the supervision and observation of a teacher. However, the groups were permitted to meet outside the data collection timings to discuss the development of their car. We considered that the students and teachers needed to complete the second prayer of the obligatory five times a day, and time is allocated during the second break for praying, while the remaining 40 minutes was allocated for discussing and building the prototype.

The initial task considers STEM concepts, as identified in the abovementioned indicators:

- STEM reasoning
- Mathematical thinking
- Spatial reasoning
- Scientific reasonin

## 6.6. **STEM PBL term planner**

A comprehensive plan was outlined for introducing various concepts to students and delivering them effectively (Figure 7). Through an interdisciplinary approach, students used their knowledge and expertise from a variety of subjects to collaborate on an integrated and innovative project. This was meant to facilitate the development of the students' skill sets, including key knowledge areas along with practical implementation and application of the modules learned, culminating in their own project creation. Throughout the project development process, teachers were encouraged to use an open-ended teaching approach, actively soliciting, and embracing students' ideas while providing guidance on analysing different scenarios and making independent decisions. In Table 9, we provide an overview of the project, outlining how the objectives of the snail car project were met.

**Figure 6.** *STEM areas covered*

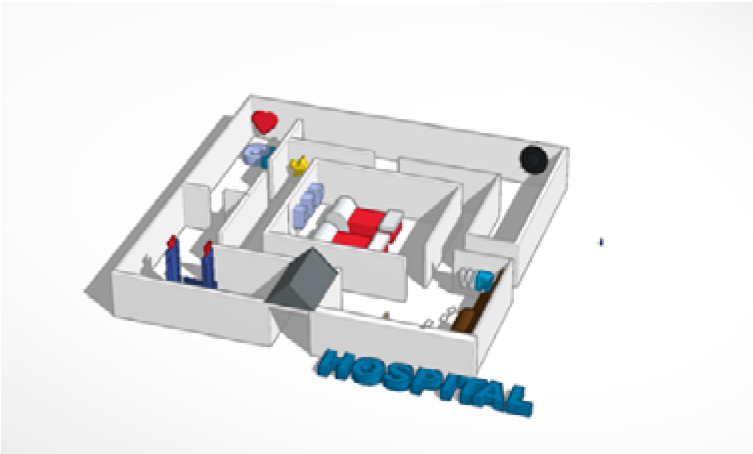
| **SCIENCE** | **TECHNOLOGY** | **ENGINEERING** | **MATHS** |
|---|---|---|---|
| Circuits<br>Current<br>Electricity<br>Velocity<br>Displacement<br>Energy consumption | ARDUINO<br>Microcontroller<br>Coding in C++<br>3D designing<br>TINKERCAD<br>Smart systems and automation | Planning<br>Designing<br>Smart technology<br>Idea analysis | Measurements<br>Area and volume<br>Equations<br>Formulas |

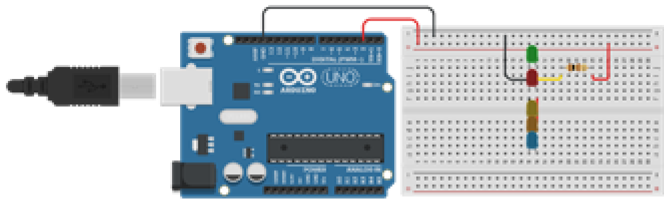
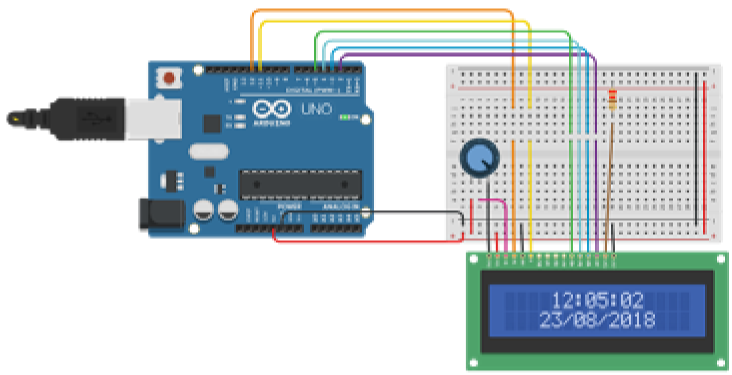
**Source:** *Own elaboration.*

As shown in Table 3, a lesson plan was presented to encourage students to develop their critical thinking skills in STEM subjects.

**Table 3.** *Lesson plan*

| WEEK | LESSON |
|---|---|
| 1 | Introduction to the various platforms to be used and briefing on the project that is to be completed over the duration of the term.<br>All crucial steps involved in creating user profiles/accounts are to be addressed in this session. |
| 2 | Tinkercad basics - Introduction to the tools of 3D designing. The crucial tools for 3D designing will be introduced to the students, and they will be challenged with a task that will require them to apply these tools to create their own creative name tag.<br>Project - Create your own innovative name tag/keychain.<br>Example:   |

| WEEK | LESSON |
|---|---|
| | To demonstrate to students how basic shapes can be combined to create various models; students will be challenged to design a complete home, school, or other architectural structure, that they see around them.<br>Project - Build your own home, school, or other architectural structure.<br>Example:<br> |

| WEEK | LESSON |
|---|---|
| 4 | Circuit Basics - Students will be educated on how to create circuits for prototyping, with the use of Arduino. They will identify the various pins of the Arduino microcontroller and develop an understanding of how current flow works in circuits.<br><br>Project - Traffic Light System |
| | Students will be briefed on how to integrate sensors into circuits. They will be taught how the sensor values can bring about changes in systems, and how feedback from various sensors can work as decision makers for different models.<br><br>Project - Automated Gate System |

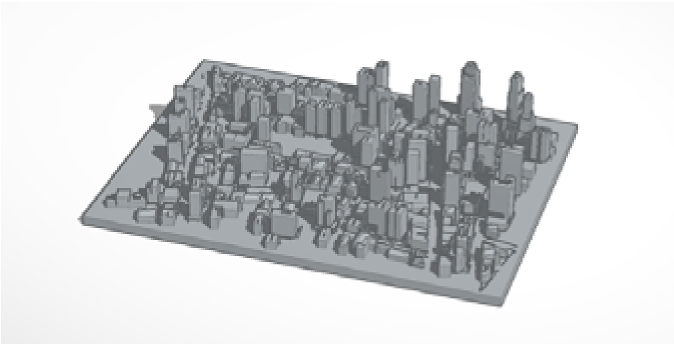
| WEEK | LESSON |
|---|---|
| 6 | Sustainable City<br>Discussion on why sustainability is important and what its benefits are, as well as why society is trying to improve sustainability. Students will be grouped into mixed-ability teams, and they will be tasked with designing a sustainable and futuristic city. They will be tasked with conducting research, they will be requested to add different features to their city, and they will be required to elaborate on how their added technology features can impact the lives of people in the city. |
| 7 | 3D Design of the Sustainable City - The complete 3D design of their planned sustainable city will be created using Tinkercad. Students will also be advised to include all the required facilities in the city.<br><br> |
| 8 | Automation - Various tools for automation should be planned for, and added to the city, as well as the circuits designed and programmed for them. Students will be tasked with developing innovative means of automation for different processes in the city, with the goal being to offer a more seamless experience for its residents. |
| 9 | Completion of circuit design and programming |
| 10 | Safety and Security<br>One of the key considerations within every city is safety. Students will be presented with hazards or calamities in different parts of their city, and they will be tasked with calculating how quickly their disaster control systems in their cities will activate. Students will have to draw from concepts learnt in mathematics to complete these challenges. |
| 11 | Preparation of their presentations |
| 12 | Presentation of their completed cities |

Table 4, Table 5, Table 6, Table 7, and Table 8 outline the allocated time for participants to complete each STEM subject activity, as well as the dates for the completion of each phase of the project.

**Table 4.** *Project Timeline*

| WEEK | TECHNOLOGY | PHYSICS | MATHEMATICS | ENGINEERING |
|---|---|---|---|---|
| Week 1 | Orientation about the course and project | | | |
| Week 2 – 5 | Define different tools available in Fusion 360.<br>Sketch different small models using Fusion 360.<br>To explore the Maker microcontroller and its hardware and programming software<br>Describe Python programming software<br>To identify different solutions for a problem, build the right algorithm and check its structure and correctness | Describe the relationship between work, energy, force, and power.<br>Define energy as the ability to do work, measured in Joules.<br>Define kinetic energy and use the equation to find the unknown quantities.<br>Define and calculate power. | Find the derivatives of functions using<br>• general power rule for polynomials.<br>• the sum and difference rules.<br>• Six basic trigonometric functions.<br>• the natural logarithm and exponential functions<br>Find antiderivatives of<br>• polynomials<br>• the six basic trigonometric functions<br>• the natural logarithmic exponential functions. | Define a gear and a gear train and calculate the gear ratio in gear trains.<br>Build a gear racer and investigate how the speed can be influenced by shifting gears.<br>Define electrical energy. List the various steps involved in generating and transmitting electrical energy and describe the function of each stage.<br>Differentiate between the operation of a motor and a generator and draw their transfer diagrams. |

Table 5. *Project Timeline (Week 2-5 continues)*

| WEEK 2-5 | TECHNOLOGY | PHYSICS | MATHEMATICS | ENGINEERING |
|---|---|---|---|---|
| Week 6 – 10 | Use a computer software package to simulate the construction and test simple and combinational DC circuits constructed in the workshop using the provided schematic diagrams. The results of testing carried out using the software should be compared to manually obtained measurements and theoretical calculated values - TINKERCAD | State and explain Newton's first and second laws of motion.<br>Apply Newton's law to objects at rest or moving with constant speed<br>Investigate the relationship between friction, normal force, and the nature of surfaces.<br>Differentiate between kinetic and static friction.<br>Relate the frictional force to the normal force graphically and find the coefficient of kinetic friction | Determine the degree of a polynomial.<br>Extract a polynomial expression form a context/ word problem.<br>Add, subtract, multiply and simply polynomials.<br>Derive a polynomial by a monomial.<br>Divide Polynomials using Long and Synthetic division.<br>Manipulate operations on polynomials modelling real-life situations such as:<br>interrelated electrical measurements, measurements of dimensions in objects and figures, etc... | Identify the main circuit components and describe their function e.g. (power source/cell (battery), load (resistance/ lamp/motor), conductor and switch)<br>Draw a schematic diagram for an electrical circuit that consists of battery, resistor/lamp, and conductor.<br>Carry out an experiment to determine the relationship between the voltage and current for a charging and discharging capacitor.<br>Describe the basics of electrical generator and how it works with reference to the electromagnetic induction.<br>Describe the basics of electrical motor and how it works with reference to the electromagnetic induction. |
| Week 11 – 14 | Use LEGO MINDSTORMS NXT robot, and program it for simple tasks using the NXT brick.<br>Program, and configure the NXT sensors including touch sensor, ultrasonic sensor, sound sensor, and light sensor for the task described.<br>Design and assemble a prototype that serves as a working solution to the problem described. | List the characteristics and draw the diagrams of series and parallel circuits.<br>Solve problems to find the current, voltages and resistances in a series and parallel circuits.<br>Calculate the voltage, current, and power dissipation for any resistor in such a network of resistors connected to a single power supply | Explain the concept of Partial fraction decomposition of a rational expression into elementary partial fractions. (broadly, the numerators of the partial fractions are of 1 degree less than their denominator)<br>Solve examples where the:<br>• Denominator has non-repeated linear factors,<br>• Rational expression is improper,<br>• Denominator has repeated linear factors,<br>• Denominator has prime quadratic factors | Describe the Electromotive force (emf) and how it is generated.<br>Describe the Faradays and Lenz's Laws<br>Demonstrate the operation of a simple power supply and the function of the individual components.<br>Identify DC circuits that consists of DC power supply and combination of series-parallel resistors.<br>Discuss half-wave and full-wave rectifier circuits and sketch the input and output waveforms.<br>Demonstrate the operation of Inverters. |

| WEEK 2-5 | TECHNOLOGY | PHYSICS | MATHEMATICS | ENGINEERING |
|---|---|---|---|---|
| Week 15 | Project Evaluation using ATHS rubric | | | |
| Week 16 | Final Exam | | | |

**Table 6.** *Timeline of Physics*

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 1 | Orientation about the Course and Project | |
| Week 2 | **1.** Differentiate between the average velocity and instantaneous velocity.<br>**2.** Differentiate between the average acceleration and instantaneous acceleration.<br>**3.** Calculate the angular velocity. | Online Quiz One |
| Week 3 | **4.** Determine functions of position, velocity, and acceleration that are consistent with each other, for the motion of an object with a non-uniform acceleration.<br>**5.** Describe the motion of an object in terms of the consistency that exists between position and time, velocity and time, and acceleration and time | Online Quiz Two |
| Week 4 | **6.** Calculate the components of a velocity, position, or acceleration vector in two dimensions.<br>**7.** Calculate a net displacement of an object moving in two dimensions.<br>**8.** Calculate a net change in velocity of an object moving in two dimensions | Online Quiz Three |
| Week 5 | **9.** Calculate an average acceleration vector for an object moving in two dimensions.<br>**10.** Derive an expression for the vector position, velocity, or acceleration of a particle, at some point in its trajectory, using a vector expression or using two simultaneous equations.<br>**11.** Calculate kinematic quantities of an object in projectile motion, such as displacement, velocity, speed, acceleration, and time, given initial conditions of various launch angles, including a horizontal launch at some point in its trajectory | Online Quiz Four |
| Week 6 | **12.** Define force and inertial frame of reference.<br>**13.** Explain Newton's first law in qualitative terms and apply the law to many different physical situations.<br>**14.** Calculate a force of unknown magnitude acting on an object in equilibrium.<br>**15.** State Newton's Second law and calculate the acceleration of an object moving in one dimension when a single constant force (or a net constant force) acts on the object during a known interval of time.<br>**16.** Calculate the average force acting on an object moving in a plane with a velocity vector that is changing over a specified time interval | Online Quiz Five |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 7 | **17.** Derive an expression for the net force on an object in translational motion.<br>**18.** Describe and calculate the static and kinetic friction.<br>**19.** Derive expressions that relate mass, forces, or angles of inclines for various slipping conditions with friction.<br>**20.** Describe an object (either in a state of equilibrium or acceleration) in different types of physical situations such as inclines and Atwood machines.<br>**21.** Derive a complete Newton's second law statement (in the appropriate direction) for an object in various physical dynamic situations (e.g., mass on incline, mass in elevator, strings/pulleys, or Atwood machines) | Online Quiz Six |
| Week 8 | **22.** Calculate a value for an unknown force acting on an object accelerating in a dynamic situation (e.g., inclines, Atwood machines, pulley systems, mass in elevator, etc.)<br>**23.** Derive an expression for the motion of an object freely falling with a resistive drag force (or moving horizontally subject to a resistive horizontal force)<br>**24.** Describe the acceleration, velocity, or position in relation to time for an object subject to a<br>**25.** resistive force (with different initial conditions, i.e., falling from rest or projected vertically)<br>**26.** Calculate the terminal velocity of an object moving vertically under the influence of a resistive force of a given relationship.<br>**27.** Derive a differential equation for an object in motion subject to a specified resistive force | Online Quiz Seven<br>Test 1 |
| Week 9 | **28.** Describe the forces of interaction between two objects (Newton's third law)<br>**29.** Describe pairs of forces that occur in a physical system due to Newton's third law.<br>**30.** Describe the forces that occur between two (or more) objects accelerating together (e.g., in contact or connected by light strings, springs, or cords)30.<br>Derive expressions that relate the acceleration of multiple connected masses moving in a system (e.g., Atwood machines) connected by light strings with tensions (and pulleys) | Online Quiz Eight |
| Week 10 | **31.** Determine the work done on an object as the result of the scalar product between force and displacement.<br>**32.** Explain how the work done on an object by an applied force acting on an object can be negative or zero.<br>**33.** Calculate work done by a given force (constant or as a given function () on an object that undergoes a specified displacement.<br>**34.** Calculate a value for work done on an object from a force versus position graph.<br>**35.** Calculate the change in kinetic energy due to the work done on an object or a system by a single force or multiple forces. | Online Quiz Nine |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 11 | **36.** Calculate the net work done on an object that undergoes a specified change in speed or change in kinetic energy.<br>**37.** Calculate changes in an object's kinetic energy or changes in speed that result from the application of specified forces.<br>**38.** Derive an expression for the rate at which a force does work on an object.<br>**39.** Calculate the amount of power required for an object to maintain a constant acceleration.<br>**40.** Calculate the amount of power required for an object to be raised vertically at a constant rate | Online Quiz Ten |
| Week 12 | **41.** Compare conservative and non-conservative forces.<br>**42.** Describe and use in calculations, the relationship between a conservative force acting in a system on an object to the potential energy of the system.<br>**43.** Describe the force within a system and the potential energy of a system.<br>**44.** Describe and calculate the spring force and work done (potential energy function) by an ideal spring.<br>**45.** Calculate the potential energy of a system consisting of an object in a uniform gravitational field | |
| Week 13 | **46.** Describe physical situations in which mechanical energy of an object in a system is converted to other forms of energy in the system.<br>**47.** Describe physical situations in which the total mechanical energy of an object in a system change or remains constant.<br>**48.** Describe kinetic energy, potential energy, and total energy in relation to time (or position) for a "conservative" mechanical system. | Online Quiz Twelve |
| Week 14 | **49.** Calculate unknown quantities (e.g., speed or positions of an object) that are in a conservative system of connected objects, such as the masses in an Atwood machine, masses connected with pulley/ string combinations, or the masses in an Adaptation Atwood machine.<br>**50.** Calculate unknown quantities, such as speed or positions of an object that is under the influence of an ideal spring.<br>**51.** Calculate unknown quantities, such as speed or positions of an object that is moving under the influence of some other non-constant one-dimensional force.<br>**52.** Derive expressions such as positions, heights, angles, and speeds for an object in vertical circular motion or pendulum motion in an arc | Online Quiz Thirteen |
| Week 15 | Project Evaluation | Project Evaluation |
| Week 16 | Revision for Final Exam | Final Exam |

Table 7. *Timeline of Engineering*

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 1 | Orientation about the Course and Project | |
| Week 2 | **1.** Define voltage (V) as a potential difference/Electromotive Force (emf) (E), current (I) and resistance (R) and identify their units; Volt (V), Ampere (A), Ohm (Ω), respectively.<br>**2.** Identify the main circuit components and describe their function e.g. (power source/cell (battery), load (resistance/lamp/motor), conductor and switch)<br>**3.** Draw a schematic diagram for a given electrical circuit using standard electronic symbols. The circuit should include a battery, a resistor or load and a conductor. The schematic diagram should be supported by a short description of the function of each component in relation to the operation of the circuit.<br>**4.** Identify a multimeter and describe its function to measure the three electrical quantities, voltage, current and resistance.<br>**5.** Use the multimeter safely to measure Electrical Quantities in simple DC Circuit | Online Quiz One |
| Week 3 | **6.** Identify the symbols of voltmeter, ohmmeter and ammeter and draw schematic diagrams of electric circuits where ammeters, voltmeters and ammeter used to measure electrical quantities and show the correct method of connecting them.<br>**7.** Identify the resistor, its function, types (fixed as carbon resistors and variable as potentiometer) and values (Ω, kΩ, MΩ)<br>**8.** Apply color-coding to determine the resistance value (four band resistors) and compare it with measured values using the multimeter<br>**9.** State Ohm's Law, identify Ohm's Law formulae (V=IR and P=IV) and describe the relationship between I, V and R | Online Quiz Two |
| Week 4 | **10.** Identify DC circuits that consists of DC power supply and resistors connected in series and parallel arrangement.<br>**11.** Draw circuit/schematic diagrams for different DC circuits where resistors are connected in series and parallel.<br>**12.** Identify the power formulae with its correct unit P=VI, P=I2R, P=V2/R<br>**13.** State Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL) and state their formulas | Online Quiz Three |
| Week 5 | **14.** Calculate the electrical quantities (voltage, current, resistance and power) in a DC circuit that consists of 3 parallel resistors or 3 series resistors and calculate the equivalent resistance the network.<br>**15.** Identify DC circuits that consists of DC power supply and combination of series-parallel resistors.<br>**16.** Calculate the electrical quantities (voltage, current, resistance and power) in circuit that consists of three series and three parallel resistors connected in a combinational arrangement with a single power supply and find the equivalent resistance.<br>**17.** Use Ohm's law and Kirchhof's laws to calculate the voltage, resistance and current in DC network that consists of least five components e.g., DC power source with two series resistor and three parallel resistors connected in a series parallel arrangement | Online Quiz Four |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 6 | **18.** Use voltage division and current division rules to find the voltage and current on a specific resistor in parallel, series and combinational DC circuits.<br>**19.** Build simple and combinational DC circuits and use the multimeter safely to measure DC electrical quantities (current, voltage, resistance) and then verify your measurements by comparing them to theoretical values.<br>**20.** Use a computer software package to simulate the construction and test simple and combinational DC circuits constructed in the workshop using the provided schematic diagrams. The results of testing carried out using the software should be compared to manually obtained measurements and theoretical calculated values. | Online Quiz Five |
| Week 7 | **21.** Define capacitor, its unit and list three of their applications depend on their values.<br>**22.** Describe the construction of a simple capacitor (Conductive plates, Dielectric)<br>**23.** Describe the Electrostatic field (E) between two charged plates, define its equation, and study the relation between its variables=<br>**24.** Draw the symbols of different capacitor types (Fixed, variable, and Electrolytic)<br>**25.** Describe the working principles of a capacitor with the aid of circuit schematics. | Online Quiz Six |
| Week 8 | **26.** Define capacitance and identify its unit.<br>**27.** Calculate the capacitance and charge in a simple circuit that consists of DC power supply connected to a capacitor in series using the formulas C=Q/V<br>**28.** Identify DC circuits that consists of DC power supply and capacitors connected in series and parallel.<br>**29.** Calculate the charge, voltage, and energy values in a DC network for both three capacitors in series and three capacitors in parallel, and find the equivalent capacitance for the network. | Online Quiz Seven<br>Test one |
| Week 9 | **30.** Explain the changes in current and voltage that occur during the charging and discharging of a capacitor together with the effect of circuit resistance and the concept of time constant.<br>**31.** Carry out an experiment to study the charging voltage curve of a given RC circuit. Explain the behaviour of the circuit in relation to the time constant =, and indicate the time needed to fully charge the capacitor with the initial condition, t=0, Q-0.<br>**32.** Draw the transient response of the voltage and current for a capacitor and resistor connected in series with a DC source in charging and discharging phases.<br>**33.** Calculate the circuit time constant for a series connected capacitor and resistor circuit, and the time required for the capacitor to be fully charged or discharged.<br>**34.** Use a computer software package to draw the charging curves, current and voltage for a given RC charging of a given RC circuit. Indicate the time needed fully charge the capacitor with the initial condition, t=0, Q-0. | Online Quiz Eight |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 10 | **35.** Identify magnetic field, magnetism, earth's magnetic field and ferromagnetic materials.<br>**36.** Describe the magnetic field patterns for a single magnetic bar and between two magnetic bars.<br>**37.** Describe the characteristics of a magnetic field that includes magnetic flux (), magnetic flux density (B), magnetomotive force (mmf), magnetic field strength (H) and permeability.<br>**38.** Identify the formulas for the magnetic field parameters and their units.<br>**39.** Calculate the magnetic field parameters for specific problems involving:<br>**40.** =, FM = NI, H = NI /l and B = H | Online Quiz Nine |
| Week 11 | **41.** Describe the Electromotive force (emf) and how it is generated.<br>**42.** Describe the galvanometer and its function.<br>**43.** Describe the Faradays and Lenz's Laws<br>**44.** Use Flaming's right-hard rule to find the direction of the current produced by electromagnetic induction including diagrams.<br>**45.** Compare between Self and Mutual inductance (L and M), and identify the unit of inductance.<br>**46.** Identify Inductors and give examples of its types.<br>**47.** Describe the basic operations of electrical generator and how it works with reference to the electromagnetic induction | Online Quiz Ten |
| Week 12 | **48.** Identify the main parts on the electrical generator.<br>**49.** Describe the basic operations of electrical motor and how it works with reference to the electromagnetic induction.<br>**50.** Identify the main parts on the electrical motor.<br>**51.** Describe with the aid of diagrams the series winding and shunt winding arrangements | Online Quiz Eleven<br>Test 2 |
| Week 13 | **52.** Describe the function of a Transformer, mention its benefits, and draw its schematic symbol.<br>**53.** Explain the concept of a transformer and describe how it works with reference to electromagnetic induction.<br>**54.** Describe the relationship between the primary and secondary voltages, current ratios, and number of turns in the primary and secondary winding | Online Quiz Twelve |
| Week 14 | **55.** Calculate values of voltage, current, turns and turn ratio for a transformer using formulas.<br>**56.** Compute the transformer secondary current when the resistive load is known.<br>**57.** Carry out a practical experiment to measure primary and secondary voltages and currents of a transformer available in the workshop under specified conditions, perform necessary calculations using /=/=/ and use a simulator to verify measurements.<br>**58.** Use a simulator or a software package available in the workshop to test the operation of an ideal transformer. Use input and output signals to verify 1/2=1/2=2/1. | Online Quiz Thirteen |
| Week 15 | Project Evaluation | Project Evaluation |
| Week 16 | Revision for Final Exam | Final Exam |

**Table 8.** *Timeline of Math*

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 1 | Orientation about the Course and Project | |
| Week 2 | **1.** Find the derivatives of functions using the general power rule for polynomials.<br>**2.** Find the derivatives of functions using the sum and difference rules.<br>**3.** Find the derivatives of the six basic trigonometric functions.<br>**4.** Find the derivatives of the natural logarithm and exponential functions.<br>**5.** Define the antiderivatives.<br>**6.** Understand the definition of antiderivative and use indefinite integral notation for antiderivatives.<br>**7.** Discuss and apply the basic integration rules.<br>**8.** Find antiderivatives of polynomials, the six basic trigonometric functions, the natural logarithm (u'/ u), and exponential functions.<br>**9.** Define a definite integral.<br>**10.** Understand the relationship between area and definite integrals. | Online Quiz One |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 3 | **11.** Define a power / monomial function as a function of the form () = $^n$ and n being non-zero real constants.<br>**12.** Describe the relationships in () = $^n$ graph's shape to the parameters:<br>- n positive integer: when odd / when even.<br>- a: when positive / when negative.<br>**13.** Graph (manually and check with graphical utility) and analyse:<br>- Monomial functions with Positive exponents.<br>- Monomial functions with Negative exponents.<br>- Monomial functions with Rational exponents.<br>**14.** Numerical application: Power Regression using and graphical utility to model the scatter plot of the data.<br>**15.** Express the Radical form into its equivalent Exponential form and vice versa. $x^{\frac{p}{n}} = \sqrt[n]{x^p}$<br>**16.** Graph (manually and check with graphical utility) and analyse:<br>**17.** Different forms of Radical functions.<br>- Describe their:<br>- Oddity (even- odd)<br>- Domain,<br>- Range<br>- Intercepts,<br>- End Behaviour,<br>- Continuity,<br>- Regions of increase or decrease.<br>**18.** Solve Radical Equations - (radicals present on one or both sides of the equality)<br>- Explain the steps needed: isolation of radical terms, power raising etc.<br>- Highlight the need to test for Extraneous solutions.<br>**19.** Interpret and solve problems reflecting real – life situations,<br>- Using the graphical representation of Power functions.<br>- (Including monomial, rational exponents, and radical functions)<br>**20.** Apply solving Radical equations to solve a variety of real-life/ scientific applications.<br>- (Agricultural sciences, optics, chemistry, electricity...) | Online Quiz Two |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 4 | **21.** Recognize that a polynomial function is a function of the form:<br>$P(x) = a_n x^n + a_{n-1} x^{n-1} + \cdots + a_2 x^2 + a_1 x + a_0$<br>**22.** Identify the terms: leading coefficient, degree, terms, coefficients, standard form of polynomial function.<br>**23.** Determine the Domain, Range, Continuity of a polynomial function given:<br>- the graph or<br>- the equation of the function.<br>**24.** Describe the End behaviour of a polynomial function given: (Leading Term Test - using limits)<br>- the degree (odd/even) and<br>- sign of the leading coefficient of the function.<br>**25.** Recognize that a polynomial function of degree  has at most –1 turning points. (local extrema)<br>**26.** Recognize that a polynomial function of degree  has at most n zeros.<br>**27.** Explain the concept of Repeated zeros / multiplicity of a zero of a polynomial function.<br>**28.** State for a given polynomial function the possible:<br>- number of real zeros,<br>- number of turning points.<br>Then determine all real zeros by factoring techniques.<br>**29.** Determine the effect of Even and Odd multiplicity on the intersection of the polynomial to the x axis:<br>**a.** if a polynomial function  has a real zero  of odd multiplicity,<br>the graph of  crosses the  –  at (, 0) and the value of  changes signs at  = .<br>**b.** if a polynomial function  has a real zero  of even multiplicity,<br>the graph of  is tangent at (, 0) to the  –  and the value of  does not change signs at  = .<br>**30.** Use the intermediate value theorem to guess a zero/root:<br>If a and b are real numbers with a < b and if f is continuous on the interval [a, b], then f takes on every value between f(a) and f(b).<br>In other words, if $y_0$ is between f(a) and f(b), then $y_0$= f(c) for some number c in [a, b].<br>If f(a) and f(b) have opposite signs, then f(c) = 0 for some c in [a, b].<br>**31.** Graph a polynomial function manually given a description of:<br>- its degree, and/or the sign of its leading coefficient.<br>- its end-behaviour,<br>- its zeros,<br>- state of multiplicity of any repeated zeros.<br>**32.** Use technological graphical tools and zooming techniques to compare graphs of polynomial functions.<br>**33.** Apply properties of polynomial functions to solve real-life, geometric applications. | Online Quiz Three |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 5 | **34.** Use Long division to divide polynomials.<br>$$f(x) = d(x) \cdot q(x) + r(x) \leftrightarrow \frac{f(x)}{d(x)} = q(x) + \frac{r(x)}{d(x)}$$<br>**35.** Use the Synthetic division Algorithm to divide polynomials.<br>**36.** Use the Remainder theorem to find the remainder:<br>"If a polynomial () is divided by – , then the remainder is = (c)"<br>**37.** Use the Factor theorem to determine whether a binomial is a factor of a polynomial using Synthetic Substitution:<br>"A polynomial () has a factor – c, if and only if () = 0"<br>**38.** Use the Rational Zero Theorem to find rational zeros of a polynomial equations.<br>"Suppose f is a polynomial function of degree n ≥ 1 of the form:<br>$f(x) = a_n x^n + a_{n-1} x^{n-1} + +a_2 x^2 + a_1 x + a_0$, where every coefficient is an integer ≠ 0.<br>If x = p / q is a rational zero of f, where p and q have no common integer factors other than ±1, then:<br>p is an integer factor of the constant coefficient $a_0$<br>q is an integer factor of the leading coefficient $a_n$."<br>**39.** Use the Upper and Lower Bound Tests to establish bounds for the real zeros of a polynomial functions: (narrow the search after Rational Zero Theorem)<br>"Let f is a polynomial function of degree n ≥ 1 with a positive leading coefficient.<br>**40.** Suppose f(x) is divided by x – k using synthetic division.<br>- If k ≥ 0 and every number in the last line nonnegative (positive or zero), then k is an upper bound for the real zeros of f<br>- -If k ≤ 0 and the numbers in the last line are alternately nonnegative and nonpositive, then k is a lower bound for the real zeros of f"<br>**41.** Understand Descartes' Rule of signs.<br>**42.** Use a combination of theorems (rational zero, factor, etc.), polynomial division (long or synthetic), factoring, and/or obtaining zeros from the graph to find all Real zeros of a polynomial equation.<br>**43.** Apply solving polynomial equations to solve physics applications with real zeros.<br>**44.** Use the Fundamental Theorem of Algebra:<br>"A polynomial function of degree n has n Complex zeros (real and non-real).<br>Some of these real zeros may be repeated" to find roots, classify roots, and to find the number of roots of a certain type.<br>**45.** Use the Linear Factorization Theorem:<br>"If f(x) is a polynomial function of degree n> 0, then f(x) has precisely n linear factors and $f(x) = a(x - z_1)(x - z_2)..(x - z_n)$ where a is the leading coefficient of f(x) and z&, z',.... z/ are the complex zeros of f(x).<br>The $z_i$ are not necessarily distinct numbers, some may be repeated." to draws connections and conclusions regarding roots/zeros of polynomial functions.<br>**46.** Use the Complex Conjugate Theorem<br>"Suppose that f(x) is a polynomial function with real coefficients. If a and b are real numbers with b ≠ 0 and a + Sqrt [b] is a zero of f(x), then its complex conjugate a – Sqrt[b] is also a zero of f(x)." to find and classify roots/zeros of polynomial functions.<br>**47.** Use the Irrational Conjugate Theorem<br>"Suppose that f(x) is a polynomial function with real coefficients.<br>If a and b are real numbers with b ≠ 0 and a + √b is a zero of f(x), then its irrational conjugate a - √b is also a zero of f(x)." to find and classify roots/zeros of polynomial functions.<br>**48.** Construct a polynomial function given the roots of the function and/or the multiplicity of the roots.<br>**49.** Use a combination of theorems (rational zero, factor, fundamental theorem of algebra, complex conjugate, irrational conjugate, etc.), polynomial division (long or synthetic), factoring, and/or obtaining zeros from the graph to find all complex zeros of a polynomial equation. | Online Quiz Four |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 6 | **50.** Recognize that a reciprocal function is of the form: () = 1/x and a transferred reciprocal function is of the form: $r(x) = \frac{a}{x \pm b} \pm c$<br>**51.** Describe the transformations a transferred reciprocal function went through.<br>**52.** Determine the domain and range of a reciprocal function given:<br>- the limits,<br>- the graph, or<br>- the equation of the function.<br>**53.** Manually sketch a transferred reciprocal function.<br>**54.** Use limits to describe the end behaviour of a reciprocal function.<br>**55.** Find the equations of vertical and horizontal asymptotes given:<br>- the limits,<br>- the graph, or<br>- the equation of a Reciprocal function.<br>**56.** Recognize that a function () = f(x) / g(x) is said to be a rational function if there exist polynomial functions  and  such that g() ≠ 0.<br>**57.** Determine the domain and range of a rational function given:<br>- the limits, or<br>- the graph, or<br>- the equation of the function.<br>**58.** Deduce that a rational function has a point of discontinuity at point c (hole) if: ( – ) is a factor of both the numerator and denominator.<br>**59.** Recognize under what conditions a rational function has a: Vertical asymptotes.<br>- Horizontal asymptotes. ( = 0  = )<br>- Obliques asymptotes.<br>**60.** Find the equations of the different types of asymptotes given:<br>- the limits, or<br>- the graph, or<br>- the equation of a rational function | Online Quiz Five |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 7 | **61.** Determine the domain of a rational equation. Specify the constraints on the values of x in the equation.<br>**62.** Solve rational equations that have monomial denominators.<br>**63.** Solve rational equations that have polynomial denominators.<br>**64.** Determine the extraneous solutions of a rational equations.<br>**65.** Recognize that that a rational equation whose solutions are all outside the domain (all solutions are extraneous) has no solution.<br>- i.e. The empty set symbolized by {} is the solution of this equation.<br>**66.** Construct a rational equation from a word problem describing real-life situation such as concentration of chemicals in a mixture, speed rates, work, etc.<br>**67.** Interpret the mathematical solution of a rational equation in a real-life/scientific context.<br>**68.** Determine the range of values on which a:<br>- polynomial function,<br>- rational function,<br>- function involving radical,<br>- function involving absolute value. is positive, negative, or zero given its equation.<br>**69.** Use table of values and signs to solve inequalities analytically.<br>**70.** Use graphing tools to solve inequalities graphically.<br>**71.** Construct an inequality from a word problem describing geometric, scientific, or real-life situation. Interpret solutions in context | Online Quiz Six |
| Week 8 | **72.** Define an exponential function.<br>**73.** Identify the graph of an exponential function.<br>**74.** Compute exponential function values for rational numbers of inputs.<br>**75.** Graph an exponential function using table of values.<br>**76.** Differentiate between exponential growth and decay.<br>**77.** Explore and apply transformations of exponential graphs.<br>**78.** Define the natural base e.<br>**79.** Study the logistic growth function and its graph. (a binary classification model for AI-ML applications)<br>**80.** Graph logistic growth function using the graphing calculator.<br>**81.** Solve real-world/scientific applications related to the exponential family of functions:<br>**a.** population models.<br>**b.** growth and decay models: continuous and discrete types.<br>**c.** financial computations of compounded and continuously compounded interest. | -Online Quiz Seven<br>-Test 1 |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 9 | **82.** Understand the logarithmic function to be the inverse of the exponential function.<br>**83.** Graph the logarithmic function and the exponential function on the same coordinate system and notice the symmetry between the two graphs along the line = .<br>**84.** Change from logarithmic form to exponential form and vice versa.<br>**85.** Study the basic properties of logarithms.<br>**86.** Define the common logarithm-Base 10 and study the basic properties of the common logarithms.<br>**87.** Evaluate logarithms and exponential expressions-Base 10.<br>**88.** Evaluate common logarithms with a calculator.<br>**89.** Solve simple logarithmic equations.<br>**90.** Define the natural logarithm-Base e and study the basic properties of the natural logarithms.<br>**91.** Evaluate logarithms and exponential expressions–Base e<br>**92.** Evaluate natural logarithms with a calculator.<br>**93.** Transform logarithmic functions.<br>**94.** Solve real world applications related to logarithmic functions such as:<br>Measure sound using decibels.<br>Hydrogen potential pH of solutions<br>Bacterial growth … | Online Quiz Eight |
| Week 10 | **95.** Identify and apply the properties of logarithms.<br>**96.** Prove the product rule for logarithms.<br>**97.** Expand the logarithm of:<br>a product<br>a quotient.<br>a power.<br>**98.** Condense logarithmic expressions.<br>**99.** Discuss and apply the change of base formula.<br>**100.** Evaluate logarithms by changing the base.<br>**101.** Solve real world applications using the logarithmic properties and re-expressing data, related to:<br>Chemistry<br>music notes/ pitch<br>earthquake activity<br>movie projections…<br>**102.** Solve a variety of exponential equations.<br>**103.** Solve a variety of logarithmic equations.<br>**104.** Solve real world applications using the logarithmic and exponential equations, related to:<br>- web traffic<br>- engine horsepower<br>- astronomy<br>- forensics<br>- radioactivity<br>- genetics-PCR… | Online Quiz Nine |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 11 | **105.** Identify the graph properties of the parent Tangent function () = = sin x / Cos x<br>- Domain and Range<br>- Period / Symmetry<br>- Intercepts<br>- Continuity<br>- Asymptotes<br>- Extrema (none)<br>- End Behaviour<br>**106.** Identify the same equivalent graph properties for the general tangent function of the form: () = · ( + ) + , of period = π/ \|b\|<br>**107.** Graph different dilations, reflections, translations of the Tangent function. (locate vertical asymptotes, table of values ...)<br>**108.** Identify the graph properties of the reciprocal Cotangent function () = = Cos x / Sin x<br>- Domain and Range<br>- Period / Symmetry<br>- Intercepts<br>- Continuity<br>- Asymptotes<br>- Extrema (none)<br>- End Behaviour<br>**109.** Identify the same equivalent graph properties for the general cotangent function of the form: () = · ( + ) + , of period = π/ \|b\| .<br>**110.** Graph different dilations, reflections, translations of the cotangent function. (locate vertical asymptotes, table of values)<br>**111.** Clarify how the graphs of the reciprocals of sine and cosine: sec can be deduced from the related and graphs.<br>Identify:<br>- Domain and Range<br>- Period / Symmetry<br>- Intercepts<br>- Continuity<br>- Asymptotes<br>- Extrema<br>- Sketch graphs of different transformed Cosecant and Secant functions.<br>**112.** Explain the idea and sketch of a Damped trigonometric function (Harmonic or not) clarify the role of the damping factor.<br>**113.** Solve real world applications of damping (mechanical, electrical) Briefly highlight frequency and amplitude modulation in radio transmission modulations (AM /FM) | Online Quiz Ten |

| TIMEFRAME | CONTENT / DELIVERABLES | ASSESSMENT |
|---|---|---|
| Week 12 | **114.** Explain the angle interpretation of the sin-1 or arcsin functions. (similarly, for $\cos^{-1}$ and $\tan^{-1}$)<br>**115.** Write and explain the reasons of the restricted domain of the inverse trigonometric functions.<br>**116.** Graph inverse sine, inverse cosine, and inverse tangent functions.<br>**117.** Solve the inverse trigonometric function with and without the aid of a calculator.<br>**118.** Solve and describe the end behaviour of the inverse sine, cosine, and tangent functions with and without the use of a calculator.<br>**119.** Compose trigonometric and inverse trigonometric functions.<br>**120.** Solving real world problems. (drag race coverage, film projection, rescue trajectories…) | -Online Quiz Eleven<br>-Test 2 |
| Week 13 | **121.** Use the:<br>**a.** Basic Trigonometric Identities<br>**b.** Reciprocal Identities<br>**c.** Co-function Identities<br>**d.** Odd-Even Identities<br>**e.** Quotient identities<br>**f.** Pythagorean Identities to prove trigonometric identities, simplify trigonometric expression and solve trigonometric equations.<br>**122.** Use combinations of the above trigonometric Identities aimed at more complex examples proving trigonometric identities, simplifying trigonometric expression, and solving trigonometric equations.<br>**123.** Solving related real-world problems.<br>**124.** Use the cosine, sine and tangent Sum or Difference Identities to find an exact value of a trigonometric function.<br>**125.** Use the cosine, sine and tangent Sum or Difference Identities to:<br>**g.** prove, verify identities.<br>**h.** simplify trigonometric expressions.<br>**i.** solve trigonometric equations.<br>**126.** Solving related real-world problems. | Online Quiz Twelve |
| Week 14 | **127.** Use the cosine, sine, and tangent of Double-Angle / Half-Angle / Power reducing Identities to:<br>- find an exact value of a trigonometric function.<br>- prove identities and solve trigonometric equations.<br>**128.** Use the Product-to-Sum / Sum-to-Product Identities to prove identities and solve trigonometric equations.<br>**129.** Solving related real-world problems.<br>**130.** Explain the concept of Partial fraction decomposition of a rational expression into elementary partial fractions. (broadly, the numerators of the partial fractions are of 1 degree less than their denominator)<br>**131.** Solve examples where the:<br>- Denominator has non-repeated linear factors,<br>- Rational expression is improper,<br>- Denominator has repeated linear factors,<br>- Denominator has prime quadratic factors, | Online Quiz Thirteen |
| Week 15 | Project Evaluation | Project Evaluation |
| Week 16 | Revision for Final Exam | Final Exam |

## 6.7. **Skills developed by the students that participated in this research**

Students participated in a hands-on prototyping process using affordable materials such as Lego components for a snail car project. It was the students' responsibility to assemble these components so that the project could be successfully completed. Students were encouraged to think creatively through project-based learning and the development of a physical prototype, which provided them with the opportunity to test their ideas, identify potential issues, conduct investigations, and make improvements accordingly to validate their conceptual understanding. Prototyping, testing, and iteratively refining the final design were all integral to the STEM PBL process. Students engaged in these activities developed their problem-solving abilities, critical thinking skills, creativity, and collaboration skills.

## 6.8. **Summary**

Chapter 6 provides a comprehensive overview of the planning and implementation processes involved in designing a 16-week course centred on STEM Project-Based Learning. By delineating the systematic steps for course development and exploring practical strategies for classroom implementation, this chapter equips educators with valuable insights and resources to enhance STEM education through PBL approaches. Moreover, the chapter introduced a framework for evaluating its effectiveness. In this chapter, we have seen the interaction between instructional methods and learning outcomes as illustrated in the stages involved with prototyping a snail car that incorporates all four STEM subjects (science, technology, engineering, and mathematics). Teachers in the STEM training program were responsible for verifying that the curriculum covered the necessary topics during the planning stage. They were also required to develop lesson plans for each STEM subject during the 16-week prototype construction period. Based on the Deming Cycle, prototyping was followed. (Appendix 21 contains photographs illustrating the construction and testing of the students' snail cars).

# SECTION IV
## STUDIES

## CHAPTER 7
## STUDY 1. EFFECTS OF PBL ON STUDENTS' INTEREST IN STEM SUBJECTS AND THE DEVELOPMENT OF CRITICAL THINKING

In this chapter, we focus on the first study of the doctoral thesis, which analyses the effects of the application of PBL in STEM subjects on students' interest in STEM subjects, as well as on the development of critical thinking. In Study 1, we examined the results derived from two modified adaptations of the STEM Semantic Survey and the Watson-Glaser critical thinking abilities questionnaire.

The implementation of the intervention programme (PBL) in an experimental group will make it possible to carry out a quasi-experimental investigation and to learn about these results.

### 7.1. Objectives and hypotheses

The study has two objectives, as stated in Chapter 4:

1. To determine how project-based learning (PBL) affects students' interest in STEM subjects.

2. To examine the impact of PBL instruction in STEM on the development of students' critical thinking skills by considering changes in their critical thinking skills before and after PBL intervention.

In order to respond to this study proposed in this thesis, the following hypotheses are formulated:

H1. The STEM interest of students who receive project-based learning (PBL) intervention will differ statistically from students who receive traditional instruction, with students receiving PBL intervention expected to be significantly more interested in STEM subjects.

H2. We will find statistically significant differences in the critical thinking skills of students receiving Project-Based Learning (PBL) instruction in STEM and students receiving traditional instruction in STEM.

## 7.2. Research design

The research design is a work plan that describes how the data collected can answer the research questions (Salkind, 2010). Although there are a number of research designs, such as case studies (Tetnowski, 2015), experimental studies (Mcleod, 2023), and quasi-experiments (Thomas, 2020c), the randomised controlled trial (RCT) (Hariton & Locascio, 2018) is considered to be the most appropriate research design in this case.

In this study, we have chosen the quasi-experimental research design for the following reasons:

- We used project-based learning as an independent variable determine the expected difference between the control and experimental groups.

- Participants were not randomly assigned to groups. Participants were divided into groups based on characteristics such as grade, age, and gender.

7.3. Population and sample

The term "population" refers either to the total number of individuals living in an area or, in this case, to the total number of subjects under study. Boslaugh (2008) argues that it is generally not feasible to include a large proportion of the general population in any study, as such a study would require a far more substantial amount of time, effort, and resources to collect, analyse, and report data. This has led researchers to develop a set of search criteria to identify participants. As an example of what potential participants' criteria should include:

- The degree to which the participants share similar characteristics.
- Included in the sampling method are the selected criteria.
- Where the participants will be located
- The availability of participants during the research period (Daniel, 2012)

Those individuals who are eligible to participate in the study are termed the target population (Polit & Beck, 2014). A target population is defined as the unit of analysis (Boslaugh, 2008) from which research draws data to generalise its findings. Research participants can also be identified by identifying subjects with similar characteristics to those in the research. As the author proceeds to explain, it is occasionally possible for the researcher to identify a target population for practical purposes by suggesting that it is the population of individuals from which the sample will be drawn (Boslaugh, 2008). The target population of this research includes students and teachers from a selected vocational high school.

The ability to generalise this research's findings to all 11$^{th}$ grade high school students is hindered by the limited availability of data. Schools don't typically share this data, and students have an extensive choice of high schools in the UAE, including Abu Dhabi Oil Company Schools (ADNOC) Ministry of Education (MOE) schools, Emirates National schools, and Indian curriculum schools. As such, the current availability of comprehensive data from 11th grade students studying STEM subjects throughout the educational spectrum in the UAE is limited, which hinders the ability to strengthen the findings and make broader generalisations.

Given this, purposive sampling was used in this study. This study included all 11th grade students enrolled in a vocational high school in Umm Al Quwain, one of the seven emirates of the United Arab Emirates. They were between the ages of 15 and 16. Boys participating in this research were involved in STEM disciplines that would enable them to pursue either engineering or computer science at the university level. The participants were evenly distributed into two groups, namely the control group and the experimental group, with each group consisting of 75 students. STEM instruction was provided to the control group using traditional teaching methods. PBL was used to teach STEM to the experimental group.

## 7.4. **Instruments and variables**

The section has been constructed as two sections according to the objectives, one for each test. Two instruments were used in this Study 1: STEM Semantics Survey and Watson and Glaser Critical Thinking Test.

### 7.4.1. Instrument 1: STEM Semantics Survey

In order to determine how Project-Based Learning (PBL) affects students' interest in STEM subjects (objective 1), we have used the STEM Semantics Survey. In the STEM Semantics Survey, we assess students' interests in science, technology, engineering, and mathematics, as well as their likelihood to pursue careers in these fields (Stelar, n.d).

The STEM Semantics Survey contains 37 questions and is scored on a 5-point Likert scale. Several studies have used this STEM Semantics Survey successfully with high school students (Çevik, 2018; Meredith et al., 2013; Zhang et al., 2022).

The original questionnaire was modified in some specific respects. The decision to modify the STEM Semantics Survey questionnaire (Table 9) was because the students' primary language was Arabic, with English their second language. It has been recognised that structuring these questionnaires in a format consistent with their familiar assessment practices can facilitate a more comfortable and effective assessment process. In addition to measuring their interest in STEM subjects and 21$^{st}$ century skills, this approach also considers their language proficiency, resulting in a more equitable assessment.

Table 9. *Adaptation STEM Semantics Survey – changes made to the original*

| **ORIGINAL STEM SEMANTICS SURVEY**<br>(Knezek & Christensen, STEM Semantics Survey, 2008) | **ADAPTATION** |
|---|---|
| • The original STEM Semantics Survey included 25 items.<br>• Items were measured on a seven-point scale.<br>• The selection options have been shifted away from strongly agree, agree and etc, to options such as "appealing, boring and exciting.".<br>• Appendix 11 provides more information. | • The Adaptation STEM Semantics Survey. Measuring the following items. Math – 8 items, Science – 9 items, Engineering and Technology – 9 items and 21$^{st}$ Century skills – 11 items.<br>• The items were measured on a 5-point Likert scale.<br>• The selection options included Strongly agree, agree etc.<br>• Appendix 10 provides more information. |

An adaptation of the STEM Semantics Survey was validated by two experts in STEM education: Mr. Kareem Ragab, Physics and Mathematics, Applied Technology High Schools, Dubai Campus; and Mr. Mohammed Abdou, Engineering Technology and Science, Applied Technology High Schools, Dubai Campus.

Table 10 and Table 11 provide a summary of the inter-rater agreement results obtained from the adaption of the STEM Semantics Survey. The experts examined the level of clarity in the questions, the suitability of the vocabulary used, and the general relevance of the survey items related to STEM disciplines and 21st-century skills. The tables provide a measure of agreement among raters, giving information about the reliability and consistency of the survey adaptation process. In this way, it is possible to determine whether the survey instrument effectively assesses students' interest in STEM subjects, as well as 21st century skills.

**Table 10.** *Adaptation STEM Semantics Survey inter-rater agreement 1*

| RATER 1 | SUBJECTS | QUESTIONS | AGREE | DISAGREE |
|---|---|---|---|---|
| Name: Mohammed Abdou | STEM subjects (Science, Technology, Engineering, Mathematics | Vocabulary: Do the terms used in the survey accurately represents concepts relevant to STEM? | * | |
| Profession: Dubai acting vice principal | | Applicability of real-world applications: Do the survey questions relate to the practical applications of STEM? | * | |
| Total experience (Yrs.): 26 | | Relevance to the curriculum: Are the topics covered in the survey aligned with the current curriculum of STEM education. | * | |
| Qualification: BSc mechanical | | Do the questions effectively gauge understanding of fundamental principles specifically in STEM subjects. | | * |
| | | Coverage: Does the survey cover a wider range of topics on STEM interest and career focus? | * | |
| | | Clarity of the Language: Are the questions presented in a manner that avoids ambiguity or confusion in interpretation? | * | |
| | | Relevance to problem-solving: Do the questions encourage critical thinking and problem-solving skills? | * | |
| | | Inclusivity of STEM fields: Are the questions in the STEM Semantics Survey easy to understand without prior specialized knowledge in STEM subjects? | * | |
| | | Alignment with learning objectives: Are the survey questions aligned with the intended learning objectives for STEM education at eleventh-grade level? | | * |

Table 10. *$21^{st}$ Century skills (continuation)*

| RATER 1 | SUBJECTS | QUESTIONS | AGREE | DISAGREE |
|---|---|---|---|---|
| Name: Mohammed Abdou | $21^{st}$ Century skills | Clarity of Skills Assessment: Are the questions in the survey clear in evaluating 21st-century skills, such as critical thinking, creativity, collaboration, and communication? | * | |
| Profession: Dubai acting vice principal | | Applicability to Diverse Contexts: Do the questions cater to assessing 21st-century skills in varied contexts, including both academic and real-world scenarios? | * | |
| Total experience (Yrs.): 26 | | Language and Vocabulary Suitability: Is the vocabulary used in the survey understandable and applicable across diverse cultural and linguistic backgrounds? | * | |
| Qualification: BSc mechanical | | Connection to Modern Challenges: Do the questions relate to contemporary challenges and scenarios that demand 21st-century skills? | * | |
| | | Assessment of Adaptability: Do the questions assess adaptability, flexibility, and the ability to learn in evolving environments? | * | |
| | | Assessment of Digital Literacy: Do the questions evaluate digital literacy and proficiency in leveraging technology for learning and problem-solving? | * | |
| | | Emphasis on Interdisciplinary Skills: Are the questions designed to evaluate interdisciplinary skills and the ability to integrate knowledge from multiple domains? | * | |
| | | Assessment of Global Awareness: Do the questions assess global awareness, cultural competence, and understanding of global issues? | * | |

Table 11. *Adaptation STEM Semantics Survey inter-rater agreement 2*

| RATER 2 | SUBJECTS | QUESTIONS | AGREE | DISAGREE |
|---|---|---|---|---|
| Name: Kareem Rajab | STEM subjects (Science, Technology, Engineering, Mathematics | Vocabulary: Do the terms used in the survey accurately represents concepts relevant to STEM? | * | |
| Profession: Dubai principal | | Applicability of real-world applications: Do the survey questions relate to the practical applications of STEM? | * | |
| Total experience (Yrs.): 29 | | Relevance to the curriculum: Are the topics covered in the survey aligned with the current curriculum of STEM education. | * | |
| Qualification: Master's degree in mechanical engineering | | Do the questions effectively gauge understanding of fundamental principles specifically in STEM subjects. | | * |
| | | Coverage: Does the survey cover a wider range of topics on STEM interest and career focus? | * | |
| | | Clarity of the Language: Are the questions presented in a manner that avoids ambiguity or confusion in interpretation? | | * |
| | | Relevance to problem-solving: Do the questions encourage critical thinking and problem-solving skills? | * | |
| | | Inclusivity of STEM fields: Are the questions in the STEM Semantics Survey easy to understand without prior specialized knowledge in STEM subjects? | * | |
| | | Alignment with learning objectives: Are the survey questions aligned with the intended learning objectives for STEM education at eleventh-grade level? | | * |

Table 11. *21st Century skills (continuation)*

| RATER 2 | SUBJECTS | QUESTIONS | AGREE | DISAGREE |
|---|---|---|---|---|
| Name: Kareem Rajab | 21st Century skills | Clarity of Skills Assessment: Are the questions in the survey clear in evaluating 21st-century skills, such as critical thinking, creativity, collaboration, and communication? | * | |
| Profession: Dubai principal | | Applicability to Diverse Contexts: Do the questions cater to assessing 21st-century skills in varied contexts, including both academic and real-world scenarios? | * | |
| Total experience (Yrs.): 29 | | Language and Vocabulary Suitability: Is the vocabulary used in the survey understandable and applicable across diverse cultural and linguistic backgrounds? | * | |
| Qualification: Master's degree in mechanical engineering | | Connection to Modern Challenges: Do the questions relate to contemporary challenges and scenarios that demand 21st-century skills? | * | |
| | | Assessment of Adaptability: Do the questions assess adaptability, flexibility, and the ability to learn in evolving environments? | * | |
| | | Assessment of Digital Literacy: Do the questions evaluate digital literacy and proficiency in leveraging technology for learning and problem-solving? | * | |
| | | Emphasis on Interdisciplinary Skills: Are the questions designed to evaluate interdisciplinary skills and the ability to integrate knowledge from multiple domains? | * | |
| | | Assessment of Global Awareness: Do the questions assess global awareness, cultural competence, and understanding of global issues? | * | |

To assess this, Cohen's Kappa was performed, Table 12 and Table 13, which quantifies the level of agreement between two interrelated categorical datasets. The Cohen's Kappa coefficient indicated a significant level of agreement between the ratings of sample rater 1 and rater 2, with a value of 0.77.

Table 12. *STEM Semantics Survey Cohen Kappa's cross table*

| | | RATER 1 | | |
|---|---|---|---|---|
| | | 1 | 0 | Total |
| RATER 2 | 1 | 14 | 0 | 14 |
| | 0 | 1 | 2 | 3 |
| | Total | 15 | 2 | 17 |

**Table 13**. *STEM Semantics Survey Cohen's Kappa's coefficient*

| COHEN'S KAPPA | P |
|---|---|
| 0.77 | .001 |

Using the Adaptation STEM Semantics Survey, we developed a questionnaire that includes 37 items that address all four major STEM fields (math, science, engineering, and technology). The questionnaire statements were rated on a 5-point Likert scale: 1. Strongly Disagree, 2. Disagree, 3. Neutral, 4. Agree, and 5. Strongly Agree. In addition, 21st century skills were included in the STEM Semantics Survey as it shows the readiness of students to enter STEM fields, as it requires critical thinking skills and collaboration.

A reliability test (Table 14) was conducted for the adaptation of the STEM Semantics Survey items. Although we made changes to the STEM Semantics Survey, substantial evidence supports its reliability. Tyler-Wood et al. (2010) reported a reliability score of 0.78 in their study. A Cronbach alpha reliability coefficient of 0.97 for the complete scale was determined by the study conducted by Çevik (2018), indicating a substantial degree of internal consistency. Based on a study conducted by Vela et al. (2020), Cronbach alpha reliability coefficients for distinct categories ranged from 0.91 to 0.93. A study conducted by Knezek et al. (2011) reported that the STEM Semantics Survey had Cronbach alpha reliability coefficients ranging from 0.71 to 0.91. In this study, reliability of the items indicates consistency with the categories established by Vela et al. (2020).

**Table 14**. *Stem Semantics Survey Cronbach alpha of the items*

| SKILLS | NO OF ITEMS | CRONBACH'S ALPHA |
|---|---|---|
| *Mathematics* | 8 | 0.87 |
| *Science* | 9 | 0.786 |
| *Engineering and Technology* | 9 | 0.92 |
| *21st Century Skills* | 11 | 0.881 |

### 7.4.2. Instrument 2: Watson and Glaser Critical Thinking Test

The Watson-Glaser critical thinking test is a multiple-choice assessment tool aligned with the definitions outlined by Bernard et al. (2008), who posited that critical thinking involves "descriptive, inferential, and verification processes." These processes are analogous to critical thinking indicators such as interpretation, explanation, analysis, and evaluation, as identified by Hapsari (2016). Gadzella et al. (1996) note that the Watson-Glaser test evaluates a candidate's ability to solve problems and gives explanations for real-life scenarios, both of which are key aspects of critical thinking. It was decided to use the Watson-Glaser test instead of the California Critical Thinking Test (CCTST) (Insight Assessment, 2023), as it is the oldest, most widely administered, and most well researched instrument for measuring critical thinking (Possin, 2014). Furthermore, research on critical thinking and STEM has proved the efficacy of administering the Watson Glaser test (Dewanti et al., 2021; Yaki, 2022). See Appendix 13 to 17.

We used adaptation version of the Watson and Glaser Critical Thinking Assessment that was validated by the following experts in the field:

- Dr. Moin Hanif. Electrical and Electronics Engineering. Science Faculty of Engineering, University of Johannesburg, South Africa.
- Amer Al Jarrah, Assistant Prof ETS (math and physics), Faculty of Engineering at Higher Colleges of Technology, UAE
- Kamal Abuqaaud, Lecturer in Engineering Technology and Science Faculty of Engineering, Higher Colleges of Technology, UAE (SeeAppendix13 and 14).

**Table 15.** *Adaptation Watson and Glaser Critical Thinking Test inter-rater agreement 1*

| | | | | |
|---|---|---|---|---|
| Expert name: | Kamal Adel Abuqaaud | | | |
| Organisation: | Higher Colleges of Technology | | | |
| **SR. NO** | **CRITERIA TO RATE** | **AGREE** | **DISAGREE** | **CODE** |
| Que.: 01 | Number of questions for theoretical and practical test are enough | * | | 1 |
| Que.: 02 | Wording of the questions is clear. | * | | 1 |
| Que.: 03 | Spelling of words is correct. | * | | 1 |
| Que.: 04 | Sentences are well structured. | * | | 1 |
| Que.: 05 | The importance of the questions is consistent with the experience. | * | | 1 |
| Que.: 06 | The questions are printed in a readable manner. | * | | 1 |
| Que.: 07 | Test instruction is clear and enough. | | * | 0 |
| Que.: 08 | The instrument is well constructed, in terms of construction and well-thought-out format. | * | | 1 |
| Que.: 09 | Difficulty level of the instrument for the participants is appropriate. | | * | 0 |
| Que.: 10 | Reasonableness of items in relation to the supposed purpose of the instrument. | * | | 1 |
| | | | | |
| Remarks: | | | | |
| Filled by: | Kamal Adel Abuqaaud | | | |
| Qualification: | PhD Electrical Engineering | | | |
| Total experience (Yrs.): | 25 | | | |
| Profession: | Faculty member - Engineering college | | | |

**Table 16.** *Adaptation Watson and Glaser inter-rater agreement 2*

| Expert name: | Amer Mahmoud Aljarrah | | | |
|---|---|---|---|---|
| Organization: | Higher Colleges of Technology | | | |
| **SR. NO** | **CRITERIA TO RATE** | **AGREE** | **DISAGREE** | **CODE** |
| Que.: 01 | Number of questions for theoretical and practical test are enough | * | | 1 |
| Que.: 02 | Wording of the questions is clear. | * | | 1 |
| Que.: 03 | Spelling of words is correct. | * | | 1 |
| Que.: 04 | Sentences are well structured. | * | | 1 |
| Que.: 05 | The importance of the questions is consistent with the experience. | | * | 1 |
| Que.: 06 | The questions are printed in a readable manner. | * | | 1 |
| Que.: 07 | Test instruction is clear and enough. | * | | 0 |
| Que.: 08 | The instrument is well constructed, in terms of construction and well- thought-out format. | * | | 1 |
| Que.: 09 | Difficulty level of the instrument for the partici-pants is appropriate. | | * | 0 |
| Que.: 10 | Reasonableness of items in relation to the sup-posed purpose of the instrument. | * | | 1 |
| | | | | |
| Remarks: | | | | |
| Filled by: | Amer Mahmoud Aljarrah | | | |
| Qualification: | PhD Applied Radiation Physics | | | |
| Total experience (Yrs.): | 23 | | | |
| Profession: | Assistant Professor - Engineering Department. | | | |

Despite the fact that three experts have been mentioned as validating the Watson and Glaser Critical Thinking Test, there is no inter-rater agreement for Dr Moin Hanif. Based on Cohen's Kappa, two inter-rater agreements are considered acceptable (DATAtab, 2024.).

As shown in Table 17, Cohen's Kappa was calculated using the online statistics calculator provided by DATAtab. We conducted an inter-rater reliability analysis of the paired samples of rater 1 and rater 2. We determined the weighted Cohen Kappa, which is a measure of agreement between two dependent categorical samples. Based upon the weighted Cohen Kappa, there was a near-perfect agreement between the rater 1 and rater 2 samples, which corresponded to an  value of 0.74.

Table 17. *Weighted Cohen's Kappa*

| WEIGHTED COHEN'S KAPPA | STANDARD ERROR | LOWER 95% CI | UPPER 95% CI | P |
|---|---|---|---|---|
| 0.74 | 0.25 | 0.25 | 1.23 | .003 |

Reliability in a study is maintained, when the research uses comparable data collection and sampling methods to studies similar in construct to it, to verify the consistency of research results. As a key component of validation, this process is essential to the research process (Rupp et al., 2010; Bloor & Wood, 2006). This is analogous to replicating the current research methodology.

To ensure the reliability of the Watson and Glaser Critical Thinking Test, we used the following methods:

- Comparing our results with those of previous studies which have investigated similar constructs (Mutakinati et al., 2018; Sayekti & Suparman, 2020). In their research, Mutakinati et al. (2018) examined the impact of STEM education implemented through project-based learning on students' critical thinking abilities. The authors employed six elements of critical thinking with a similar notion to the six levels of critical thinking proposed by Elder and Paul (2010), as depicted in Figure 2. In this research, a criterion identical to the one in Elder and Paul's research, was used to assess the progress of critical thinking skills in students receiving STEM instruction through PBL. Mutakinati et al. findings (2018) revealed that students' critical thinking skills increased with PBL. The research found that 41.6% of the 160 participants were advanced thinkers, and 30.6% were practicing thinkers. In this research, PBL is also used to teach STEM, which improves students' critical thinking skills, as shown by Sayekti and Suparman (2020).

- We ensured that the same questions were asked of all interview participants.

Tests, such as those assessing critical thinking skills, can produce consistent results if the same variables and procedures are repeated over and over again. It follows that a test that adheres to the persistence standard is free from random errors and is likely to produce similar results upon repetition. A test's consistency is an important factor in determining its quality, with an ideal range falling between 0% and 1%.

### 7.4.3. Variables

The direction and outcome of the hypothesis are influenced by independent and dependent variables. Using the hypothesis as a guide, we can estimate how the independent variable will affect the dependent variable (Allen, 2017).

The independent variable for this research was project-based learning as an intervention treatment. The learning environment can influence project-based learning effectiveness. The dependent variables included critical thinking measured through five component skills: inference, recognition of assumptions, deduction, interpretation, and evaluation of arguments.

## 7.5. Procedures and pilot test

We administered the STEM Semantics Survey using JotForm, which students were given after the PBL intervention. To assure anonymity, STEM Semantics Survey participants were not required to provide their names on the test sheets. The decision not to conduct pre- and post-tests for the STEM Semantics Survey was based on empirical evidence from studies with similar constructs such as Perez (2019), Tyler-Wood et al. (2010) and Zhang et al. (2022) were consulted and did not employ pre- and post-tests in their STEM Semantics Survey. This decision is consistent with the findings of the studies mentioned above.

### 7.5.1. Watson and Glaser Critical Thinking Pilot Test

Using two Adaptation versions of the Watson and Glaser Critical Thinking Assessment, we conducted a pilot study on 50 11$^{th}$-grade vocational high school boys. Pilot study participants were from the Fujairah campus in the Northern Emirates. The pilot studies were conducted in February 2020, before students began attending remote classes. Each component of the questionnaire was explained in detail to students prior to completion. To clarify the instructions, it was helpful to include information about the components of the questionnaire. We gained valuable information from the pilot studies regarding how long it takes to fill out each questionnaire. It took approximately one hour, and twenty minutes were devoted to completing the critical thinking skills survey, based on the last submission of the questionnaire to the teacher.

The Spearman correlation test was used in the pilot study. As shown in Table 18, the internal validity of the critical thinking skills test has been determined based on the results of a pilot study conducted with 50 students.

**Table 18.** *Internal validity of the Watson and Glaser Critical Thinking Skills Test pilot study*

| CRITICAL THINKING DIMENSIONS | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Inference | 1 | | | | |
| 2. Recognition of assumptions | 0.911** | 1 | | | |
| 3. Deduction | 0.948** | 0.914** | 1 | | |
| 4. Interpretation | 0.930** | 0.949** | 0.952** | 1 | |
| 5. Evaluation of arguments | 0.748** | 0.880** | 0.828** | 0.873** | 1 |

***Note***: *** Correlation is significant at the 0.01 level*

Table 19 presents the Spearman correlation coefficient used for assessing the critical thinking knowledge of the participants during the pre-test phase of the pilot study. This statistical measure was employed to calculate the scores between the test and each individual item on the test.

**Table 19.** *Pilot study results of the Spearman correlation coefficient on the Watson and Glaser Critical Thinking Skills Test*

| QUESTIONS | THEORY PART | PRACTICAL PART |
|---|---|---|
| | **Correlation coefficients** | **Correlation coefficients** |
| **Theory** | | |
| Question (1) | 0.444** | 0.318* |
| Question (2) | 0.454** | 0.422** |
| Question (3) | 0.533** | 0.391* |
| Question (4) | 0.780** | 0.403** |
| Question (5) | 0.515** | 0.326* |
| Question (6) | 0.506** | 0.319* |
| Question (7) | 0.471** | 0.322* |
| Question (8) | 0.403** | 0.472** |
| Question (9) | 0.758** | 0.560** |
| Question (10) | 0.321* | 0.3.20* |
| Question (11) | 0.368** | 0.422** |
| Question (12) | 0.819** | 0.422** |
| Question (13) | | 0.567** |

***Note**: -** Correlation is significant at the 0.01 level. -* Correlation is significant at the 0.05 level.*

The Cronbach alpha for the pilot study is shown in Table 20.

**Table 20.** *Cronbach alpha of the pilot study*

| SKILLS | NO OF ITEMS | CRONBACH'S ALPHA |
|---|---|---|
| *Inference* | 17 | 0.752 |
| *Recognition of assumptions* | 17 | 0.691 |
| *Deduction* | 17 | 0.712 |
| *Interpretation* | 18 | 0.652 |
| *Evaluation of arguments* | 12 | 0.701 |
| *Overall Critical Thinking Skill* | **25** | **0.783** |

Cronbach's alpha is shown in Table 21 for the final application of the questionnaire.

**Table 21.** *Cronbach alpha of the final application of the questionnaire*

| SKILLS | NO OF ITEMS | CRONBACH'S ALPHA |
|---|---|---|
| *Inference* | 17 | 0.826 |
| *Recognition of assumptions* | 17 | 0.749 |
| *Deduction* | 17 | 0.769 |

| | | |
|---|---|---|
| *Interpretation* | 18 | 0.776 |
| *Evaluation of arguments* | 12 | 0.753 |
| *Overall Critical Thinking Skill* | **25** | **0.841** |

## 7.6. Data analysis

For the STEM Semantics Survey, the following tests were conducted on SPSS V26:

- Descriptive statistics (Knezek et al., 2011).
- Relative Importance Index (RII). Relative Importance Index (RII) is used to examine structured questionnaire responses containing ordinal attitude measurements. Based on the questionnaire responses, the relative significance of various factors or variables can be quantified. By allocating weights to each level of the ordinal scale, the RII facilitates the determination of the relative significance of various attitudes and opinions expressed by respondents.

The following tests were conducted on SPSS version 26 for Watson and Glaser Critical Thinking Test:

- Descriptive statistics (Bani-Hamad & Abdullah, 2019; Kaur et al., 2018).
- Mann-Whitney U test, (Cloete, 2018; Orhan & Ay, 2022).
- Kolmogorov-Smirnov test and the Shapiro-Wilks test (Ahdhianto et al., 2020; (Rahman et al., 2021).
- Levene test (Suardana et al., 2019; Wahyud et al., 2019).
- Chi-Square Test for Independency (Ellahi & Sharif, 2020; Sughra & Usmani, 2022).
- Wilcoxon Test (Liu et al., 2022; Tan et al., 2023).

## 7.7. Ethics procedure

We adhered to the guidelines and ethical considerations of the World Health Organization (2011) for the inclusion of human participants in the current study, as listed below:

### Scientific design and conduct of the research

Human participation in research is only ethically justified if the research is conducted using appropriate data collection instruments pertaining to the study. Moreover, the World Health Organization (2011) has stated that research that is not scientifically supported poses potential health and safety risks to participants.

By obtaining the consent of the management of the vocational school to conduct the study, we were able to ensure that the study is scientifically supported. A consent letter was submitted to the University of Cordoba. (Appendix 7).

### Risks and potential benefits

World Health Organization (2011) states that in ethically acceptable research, risk has been reduced through safeguards that protect research participants from harm and mitigate their damaging impacts to enhance the quality of the study. There was no risk to the students in this study. Throughout the construction of the snail car, we ensured that the students wore facemasks. Furthermore, students were required to have a valid PCR test valid for seven days, which had to be repeated every five days prior to entering school. Additionally, they were required to show proof that they had been vaccinated. PCR tests and vaccinations were also required of teachers participating in this to improve the quality of a study, the World Health Organization's (2011) guidelines for ethical research advise that measures should be taken to minimize risks to research participants and prevent harm or negative impacts.

There was no risk involved in the present study, which ensured the safety of the students. A strict safety protocol was followed during the construction of the snail car, including the use of face masks by all students. Furthermore, students were required to present a valid negative PCR test result, which was required to be renewed every five days, as well as proof of vaccination before entering the school premises. The participating teachers were also required to meet similar safety requirements.

### Selection and recruitment of research participants

The World Health Organization's (2011) ethical guidelines for research emphasize that participants should not be subjected to undue burdens or asked to contribute beyond what is appropriate for their voluntary participation in the study. Furthermore, the sampling methods and sample selection should be performed in accordance with the research objectives.

For the purpose of this study, the students were asked to devote only forty minutes per session, which was limited to two weekdays and two Saturdays per month. Taking this measure was intended to ensure that the students would not be overburdened with work and that their participation would be strictly voluntary.

### Inducements, financial benefits, and financial costs

Considering the ethical guidelines of the World Health Organization (2011), it is appropriate to reimburse participants for any expenses incurred during participation in the study. Despite this, the guidelines caution against offering excessive compensation that may influence participants to participate against their better judgment or compromise their understanding of the research. The only benefit that the students received in the present study, was an additional mark on their homework. The compensation is not substantial enough to induce the students to participate against their will or to interfere with their understanding of the study.

### Protection of research participants' privacy and confidentiality

It has been noted by the World Health Organization (2011) that violating the privacy and confidentiality of research participants may be viewed as a form of disrespect and result in their withdrawal from future involvement in the study.

### Informed consent process

A fundamental ethical principle of research is the respect for the individual. Informed consent is based on this principle. According to the guidelines outlined above, we recognise the importance of safeguarding participant rights and utilizing current research to enhance UAE educational initiatives. We intend to respect any participant's decision to withdraw from the study in the future, as well as to acknowledge any relevant literature used during the research. In addition, we have not suppressed or withheld any findings or results.

Considering the study participants are under the age of 18, a written consent letter was sent via email to their parents outlining the study's purpose and procedures. Furthermore, the consent form stated that the students' participation was voluntary and that they would be interviewed at the conclusion of the study. It was necessary to obtain the consent of the parents, to be able to record the interviews. To comply with guidelines published by the World Health Organization (2011) on human participation, parents were provided with a consent form that was prepared in English and detailed the research study. As a compensation for their participation, we provided additional homework marks to students who took part in the study.

The survey data for this study was collected in September 2020. The Watson-Glaser Critical Thinking and STEM Semantics Surveys took one day to complete, and both the control and experimental groups participated in the same survey. As we conducted interviews, we adopted a relativism-based ethical stance, which argues that morality is dependent on cultural norms (Velasquez et al., n.d.). Due to our Emirati heritage, it was necessary for us to consult with the parents and obtain their consent prior to conducting interviews. It is important to view informed consent as a continuous process, especially when it is applied to mixed methods research methodologies that utilize quasi-experiments and student interviews as a method of gathering data.

As a part of the informed consent process, it was crucial that we showed respect and consideration to the parents, who had the option of allowing or declining their child's participation in the study. The decision to participate ultimately rests with the child, as stated in the consent form. It was through this approach that the dignity and autonomy of the child were respected, and the process was not considered to be detrimental to the child's best interests.

## 7.8. Results

Results are detailed in two sections. First, we discuss the results of the STEM Semantics Survey. Next, we present the results of Watson and Glaser's Critical Thinking Test.

### 7.8.1. STEM Semantics Survey Results

An analysis of the results of the Adaptation of the STEM Semantics Survey (Education Development Center, 2024) is presented in this section. The goal of the STEM Semantics Survey was to determine whether students are interested in STEM subjects.

The mean average score and standard deviation are used as measures of central tendency in descriptive statistics. By analysing participant responses, descriptive statistics can be used to identify relevant benchmarks. This instrument is particularly useful for categorising priorities based on Likert scales, which allows identification of prevalent trends. This technique is appropriate when attempting to identify the most influential factors within a significant group of participants. In many cases, Relative Importance Indexes (RIIs) are presented as percentage averages; they can be calculated in the following manner:

$$RII = \frac{\sum_{i=1}^{n} W_i n_i}{A \times N} \times 100 \qquad (0 \leq RII \leq 1)$$

Each of the responses is weighed on the following scale as follows:

- The Likert Scale ranges from 1 - 5, where the lowest value is "strongly disagree" and the highest value is "strongly agree."
- The total number of responses is represented by one mark per response.
- The highest weighing scale (value 5 per Likert scale); the total number of participants.

The Relative Importance Index ranges are explained in Table 22. As shown in Table 22, relative importance can be divided into three categories: low, medium, and high. It is implied that a result deemed low in importance has a relatively small role to play in the analysis. Medium importance implies a moderate influence on the analysis or outcome.

**Table 22.** *Relative Importance Index Coefficients Interpretation*

| RII VALUES | IMPORTANCE LEVEL | |
|---|---|---|
| 0.0 ≤ RII ≤ 0.2 | Low | L |
| 0.2 ≤ RII ≤ 0.4 | Low – Medium | L-M |
| 0.4 ≤ RII ≤ 0.6 | Medium | M |
| 0.6 ≤ RII ≤ 0.8 | Medium – High | M-H |
| 0.8 ≤ RII ≤ 1.0 | High | H |

Table 23 presents the findings regarding the importance of interest in STEM subjects among experimental and control groups. Students' interest to pursue STEM subjects as a career were positively impacted by the PBL in the experimental group.

**Table 23.** *Descriptive statistics of the STEM Semantics Survey*

| SECTION | GROUPS | MEAN | STD. DEV. | RII | IMPORTANCE LEVEL | MEAN DIFFERENCE |
|---|---|---|---|---|---|---|
| ***Mathematics*** | Experimental | 4.1033 | 0.558 | 0.821 | High | 0.7866 |
| | Control | 3.3167 | 0.499 | 0.663 | Medium–High | |
| ***Science*** | Experimental | 4.0163 | 0.654 | 0.803 | High | 0.6356 |
| | Control | 3.3807 | 0.474 | 0.676 | Medium–High | |
| ***Engineering and Technology*** | Experimental | 4.0889 | 0.726 | 0.818 | High | 0.9452 |
| | Control | 3.1437 | 0.523 | 0.629 | Medium–High | |
| ***21st Century Skills*** | Experimental | 4.0945 | 0.521 | 0.819 | High | 0.8206 |
| | Control | 3.2739 | 0.515 | 0.655 | Medium–High | |
| ***Summary of all the questions*** | Experimental | 4.0758 | 0.545 | 0.815 | High | 0.7970 |
| | Control | 3.2788 | 0.406 | 0.656 | Medium–High | |

Below are the specific findings for each subject area:

PBL has led to an increase in the students' average mathematics score from 66.3% to 82.1%, which corresponds to an increase in the students' awareness of mathematics of 3.7%).

Science scores have improved significantly from 67.6% to 80.3% among students. Based on this significant increase, it appears that PBL has successfully enhanced students' understanding of the significance of science, resulting in a mean average improvement of 18.8%.

In both engineering and technology, the PBL strategy has led to an increase in students' interest in engineering and technology from 65.5% to 81.9%, with a mean average of 30.1%).

PBL model has improved students' acquisition of 21st century skills from 65.5% to 81.93% with a mean average of 25.1% for the 21st century skills.

To determine the statistical differences between the averages of the experimental and control groups, and independent sample test was used. It is specified that the coefficient factor must be sequentially independent on two levels; thus, a normal distribution must be followed with the data showing similar differences between the two groups for the coefficient factor to follow the test. As a result, the correlation factor can be calculated mathematically.

$$t_{\underline{X}_1-\underline{X}_2} = \frac{\underline{X}_1-\underline{X}_2}{s_{\underline{X}_1-\underline{X}_2}}$$

Whereas: X̄1, X̄2

The above shows the average of both the first and the second independent groups.

$$s_{\underline{X}_1-\underline{X}_2}$$

The above shows the difference in standard deviation between the averages of the two independent groups.

Kendall tau-b:

It is a calculation used for measuring the degree of relation, or the correlation between two statistical variations, and is dependent on the indicated values observed. It is very similar to the Spearman coefficient correlation but is far superior to the Spearman method in terms of measuring the correlation of the ranks, and the values are smaller than the values of Pearson and Spearman. This coefficient can be mathematically obtained as follows.

$$\hat{\tau} = \frac{C-D}{\frac{1}{2}n(n-1)}$$

As D – c: the total difference between the values of the ranks

N: the number of pairs of values (sample)

Tables, 24, 25, 26, and 27 present the relative importance index results.

These tables show the mean average that can be calculated from the average level of the questionnaire statements for both sample groups, which makes comparison far easier. The results displayed in the table allow one to observe the effect project-based learning has on students' attitudes towards STEM.

Table 24 shows that 60% of the participants in the control group found math to be difficult, based on the RII of the responses to the question. The RII average for the statement "I can succeed in math" increased to 73%. As a result, eight of the statements were above average, and one was at the average level.

A RII value of greater than 90% is observed in three statements by members in the experimental group. In the first statement, students do not find mathematics difficult, with an RII value of 92%; in the second statement, students have a strong opinion that mathematics is their most enjoyable subject, with a RII of 91.44%; and in the third statement, students are considering careers involving mathematics, with a RII of 91.2%.

In two more statements, the RIIs were close to 90%. First, "I am the type of student who excels at mathematics," with an RII of 88.6%, and second, "mathematics is an easy subject for students," with an RII of 82.6%. Finally, "I am a good math student," with an RII of 62.4%. Therefore, five of the selected statements had a high level of importance, while one had an RII that was slightly above average.

**Table 24.** *Relative importance index results for the mathematics questions*

| ITEMS | EXPERIMENTAL GROUP | | | CONTROL GROUP | | |
|---|---|---|---|---|---|---|
| | RII | Ranking | Importance level | RII | Ranking | Importance level |
| **Mathematics** | | | | | | |
| 1.1: "Math has been my worst subject." | 0.914 | 2 | H | 0.672 | 4 | M-H |
| 1.2: "I would consider choosing a career that uses math." | 0.912 | 3 | H | 0.664 | 5 | M-H |
| 1.3: "Math is hard for me." | 0.826 | 5 | H | 0.600 | 8 | M |
| 1.4: "I am the type of student to do well in math." | 0.886 | 4 | H | 0.680 | 3 | M-H |
| 1.5: "I can handle most subjects well, but I cannot do a good job with math." | 0.920 | 1 | H | 0.648 | 6 | M-H |
| 1.6: "I am sure I could do advanced work in math." | 0.710 | 7 | M-H | 0.630 | 7 | M-H |
| 1.7: "I can get good grades in math." | 0.774 | 6 | M-H | 0.730 | 1 | M-H |
| 1.8: "I am good at math." | 0.624 | 8 | M-H | 0.682 | 2 | M-H |

Based on the results in Science (Table 25) the RIIs of the nine statements derived from the control group range between 58.4% and 78.4%, which indicates that five of the selected statements had a higher importance than average, while only four had a medium importance. Participants in the control group had the lowest RII for statements related to their need for science in their future careers and their overall self-confidence in their scientific abilities.

A RII of 84 is observed for the statement, "Knowing science will help me earn a living." After that, a statement stating "I could do advanced science work" with an RII of 83.2% was followed. The statement "I would consider a career in science," with an RII of 82.4%, raised the question of whether the students were really interested in such a career. In terms of students' opinions concerning whether they can excel in this subject, an RII of 81% was observed. In contrast, when students were asked whether knowledge gained in science would help them in their future career, an RII of 79.4% was observed. Further, when students were asked whether science is an important part of their professional lives, the RII decreased to 75.4%. Despite not being as high as some of the other RIIs observed between experimental group responses, this value is still considered to be significantly greater than the mere 58.4% observed for the same query asked of the control group. In this way, STEM PBL can be substantiated and demonstrated.

Table 25. *Relative importance index results for the science questions*

| ITEMS | EXPERIMENTAL GROUP | | | CONTROL GROUP | | |
|---|---|---|---|---|---|---|
| | RII | Ranking | Importance level | RII | Ranking | Importance level |
| **Science** | | | | | | |
| 2.1: "I am sure of myself when I do science." | 0.792 | 6 | M-H | 0.784 | 1 | M-H |
| 2.2: "I would consider a career in science." | 0.824 | 3 | H | 0.742 | 3 | M-H |
| 2.3: "I expect to use science when I get out of school." | 0.790 | 7 | M-H | 0.750 | 2 | M-H |
| 2.4: "Knowing science will help me earn a living." | 0.846 | 1 | H | 0.750 | 2 | M-H |
| 2.5: "I will need science for my future work." | 0.794 | 5 | M-H | 0.712 | 4 | M-H |
| 2.6: "I know I can do well in science." | 0.810 | 4 | H | 0.584 | 6 | M |
| 2.7: "Science will be important to me in my life's work." | 0.754 | 9 | M-H | 0.584 | 6 | M |
| 2.8: "I can handle most subjects well, but I cannot do a good job with science." | 0.786 | 8 | M-H | 0.584 | 6 | M |
| 2.9: "I am sure I could do advanced work in science." | 0.832 | 2 | H | 0.598 | 5 | M |

Using the data in Table 26, engineering and technology demonstrate no significant difference in importance over mathematics and science based on questionnaire results, except that engineering-related statements have a low relative importance when compared to the control group, ranging from 57.8% to 67.8%. Through PBL, students can discover new breakthrough technologies, whether they are products or solutions for services, demonstrating the relevance of STEM disciplines and PBL to their future careers. Furthermore, participants in the experimental group with high RII scores responded favourably to subsequent career-related questionnaires.

**Table 26.** *Relative importance index results for the engineering and technology questions*

| ITEMS | EXPERIMENTAL GROUP | | | CONTROL GROUP | | |
|---|---|---|---|---|---|---|
| | RII | Ranking | Importance level | RII | Ranking | Importance level |
| **Engineering and Technology** | | | | | | |
| 3.1: "I like to imagine creating new products." | 0.782 | 8 | M-H | 0.578 | 6 | M |
| 3.2: "If I learn engineering, then I can improve things that people use every day." | 0.814 | 5 | H | 0.670 | 2 | M-H |
| 3.3: "I am good at building and fixing things." | 0.840 | 3 | H | 0.578 | 6 | M |
| 3.4: "I am interested in what makes machines work." | 0.832 | 4 | H | 0.592 | 5 | M |
| 3.5: "Designing products or structures will be important for my future work." | 0.870 | 1 | H | 0.630 | 4 | M-H |
| 3.6: "I am curious about how electronics work." | 0.866 | 2 | H | 0.674 | 1 | M-H |
| 3.7: "I would like to use creativity and innovation in my future work." | 0.798 | 7 | M-H | 0.674 | 1 | M-H |
| 3.8: "Knowing how to use math and science together will allow me to invent useful things." | 0.808 | 6 | H | 0.632 | 3 | M-H |
| 3.9: "I believe I can be successful in a career in engineering." | 0.752 | 9 | M-H | 0.630 | 4 | M-H |

Table 27 shows the average importance level for the control group participants for the skills required in the 21$^{st}$ century, ranging from 61.6% to 70.6%. Statements related to this category scored slightly higher than average (medium) RIIs. The RIIs among the experimental group participants ranged from 75% to 86.4%. The statement observing the highest average importance level was the one related to the students' ability to selectively complete tasks and – essentially – allocate their time effectively; this questionnaire entry observed an RII of 86.4%. The RII of 85.8% was determined by students' evaluations of their ability to collaborate effectively with classmates from a variety of backgrounds. "I am certain that I can generate high-quality work," noticed a RII of 85.6%. It was observed that students' abilities to manage their time while on their own had an RII of 84.6%; their ability to adapt to circumstances when faced with new challenges was 82.4%; and the ability to set one's own learning goals had an RII of 80.8%. "I am confident I can urge others to accomplish their best," with a RII of 79.2%, and "I am confident I can lead others to attain a goal," with a RII of 75%, were the two least notable outcomes chosen for analysis.

Table 27. *Relative importance index results for the 21st Century relevant skills questions*

| ITEMS | EXPERIMENTAL GROUP | | | CONTROL GROUP | | |
|---|---|---|---|---|---|---|
| | RII | Ranking | Importance level | RII | Ranking | Importance level |
| **21st-Century Relevant Skills** | | | | | | |
| 4.1: "I am confident I can lead others to accomplish a goal." | 0.750 | 10 | M-H | 0.672 | 4 | M-H |
| 4.2: "I am confident I can encourage others to do their best." | 0.792 | 7 | M-H | 0.698 | 2 | M-H |
| 4.3: "I am confident I can produce high quality work." | 0.856 | 3 | H | 0.616 | 10 | M-H |
| 4.4: "I am confident I can respect the differences of my peers." | 0.846 | 4 | H | 0.616 | 10 | M-H |
| 4.5: "I am confident I can help my peers." | 0.776 | 9 | M-H | 0.694 | 3 | M-H |
| 4.6: "I am confident I can include others' perspectives when making decisions." | 0.790 | 8 | M-H | 0.618 | 9 | M-H |
| 4.7: "I am confident I can make changes when things do not go as planned." | 0.824 | 5 | H | 0.626 | 8 | M-H |
| 4.8: "I am confident I can set my own learning goals." | 0.808 | 6 | H | 0.656 | 5 | M-H |
| 4.9: "I am confident I can manage my time wisely when working on my own." | 0.846 | 4 | H | 0.654 | 6 | M-H |
| 4.10: "When I have many assignments, I can choose which ones need to be done first." | 0.864 | 1 | H | 0.706 | 1 | M-H |
| 4.11: "I am confident I can work well with students from different backgrounds." | 0.858 | 2 | H | 0.646 | 7 | M-H |

**Note:** *M indicates medium importance; M-H indicates medium-high importance; and H indicates high importance. (*) These questions are reversed, and as such, the students' responses are reversed.*

### 7.8.2. Watson and Glaser Critical Thinking Test Results

The Watson Glaser Critical Thinking Appraisal is a test that measures an individual's ability to assess, evaluate, interpret, rationalise, and draw logical inferences. It has been revised and enhanced multiple times (Pearson, 2020; Sternod & French, 2016) for high school students (Aiyub et al., 2021; Orhan & Ay, 2022). This section contains the results of the Watson and Glaser Critical Thinking test, including the results of pre-test and post-test.

*7.8.2.1. Pre-test results (experimental and control groups)*

A critical thinking assessment is essential prior to the implementation of project-based learning (PBL) both in the experimental and control groups. By providing actionable insights into the efficacy of problem-based learning (PBL), this assessment facilitates informed decision-making about strategies for improving critical thinking skills.

The participants were tested on the five dimensions of critical thinking skills, such as interference, recognition of assumptions, deduction, interpretation, and evaluation of arguments.

The pre-test critical thinking questionnaire included both theoretical and practical questions. It was intended that the theory questions would stimulate critical thinking and intellectual exploration in students by testing the principles, assumptions, and implications of a given topic. A calculator was not required for answering the theoretical questions but required for the practical questions.

In Table 28, the percentages of correct answers in the theoretical and applied critical thinking skills test are shown for both the experimental and control groups. Students' answers were found to be of varying degrees of correctness. In the critical thinking skill test, no question received a 100% correct response rate, indicating that answers to the questions differed,

Based on the analysis, approximately 20% to 74% of participants correctly answered the questions in the critical thinking skill test. In addition, it was found that certain questions were particularly challenging, since a relatively low number of correct responses were received. Only 22% of the total sample of participants effectively answered questions 6 and 10 in the theoretical section, and questions 10 and 11 in the applied section. As part of the theoretical questions, principles, assumptions, and implications of a given topic were tested to stimulate critical thinking and intellectual exploration in the students. As with the practical questions, the theoretical questions did not require the use of a calculator.

Table 28. *Results of the pre-test experimental and control group critical thinking correct answers*

| QUESTIONS | | EXPERIMENTAL GROUP | | CONTROL GROUP | |
|---|---|---|---|---|---|
| | | Frequency | % | Frequency | % |
| **Theory** | | | | | |
| | Question (1) | 24 | 32 | 23 | 30.7 |
| | Question (2) | 54 | 72 | 55 | 73.3 |
| | Question (3) | 46 | 61.3 | 44 | 58.7 |
| | Question (4) | 53 | 70.7 | 54 | 72 |
| | Question (5) | 24 | 32 | 25 | 33.3 |
| | Question (6) | 16 | 21.3 | 14 | 18.7 |
| | Question (7) | 56 | 74.7 | 55 | 73.3 |
| | Question (8) | 22 | 29.3 | 21 | 28 |
| | Question (9) | 29 | 38.7 | 27 | 36 |
| | Question (10) | 18 | 24 | 17 | 22.7 |
| | Question (11) | 46 | 61.3 | 21 | 28 |
| | Question (12)s | 24 | 32 | 18 | 24 |
| **Practical** | | | | | |
| | Question (1) | 26 | 34.7 | 24 | 32 |
| | Question (2) | 25 | 33.3 | 55 | 73.3 |
| | Question (3) | 46 | 61.3 | 14 | 18.7 |
| | Question (4) | 47 | 62.7 | 51 | 68 |
| | Question (5) | 24 | 32 | 14 | 18.7 |
| | Question (6) | 17 | 22.7 | 17 | 22.7 |
| | Question (7) | 16 | 21.3 | 23 | 30.7 |
| | Question (8) | 47 | 62.7 | 23 | 30.7 |
| | Question (9) | 24 | 32 | 23 | 30.7 |
| | Question (10) | 15 | 20 | 17 | 22.7 |
| | Question (11) | 16 | 21.3 | 51 | 68 |
| | Question (12) | 24 | 32 | 20 | 26.7 |
| | Question (13) | 21 | 28 | 14 | 18.7 |

For both the experimental and control groups, we used various numerical and diagrammatic techniques to assess the normal distribution of the critical thinking skills test scores. For example, we used the Kolmogorov-Smirnov test to analyse numerical data, and the Shapiro-Wilk test to compare correct responses within one standard deviation among participants. Table 27 illustrates the normal distribution of critical thinking test results for both groups regarding dimensions, interference, recognising assumptions, deduction, interpretation, and evaluating arguments.

The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests are presented in Table 29. According to the results, p-values were greater than 0.05 for both the overall critical thinking skills test and all subskills' tests, including interference, recognizing assumptions, deduction, interpretation, and evaluating arguments. Additionally, the normal distribution test, while also providing statistical references at 1% and 5% significance levels. Based on these findings, we accept the alternative assumption (H1), which implies that these variations do not adhere to a normal distribution model.

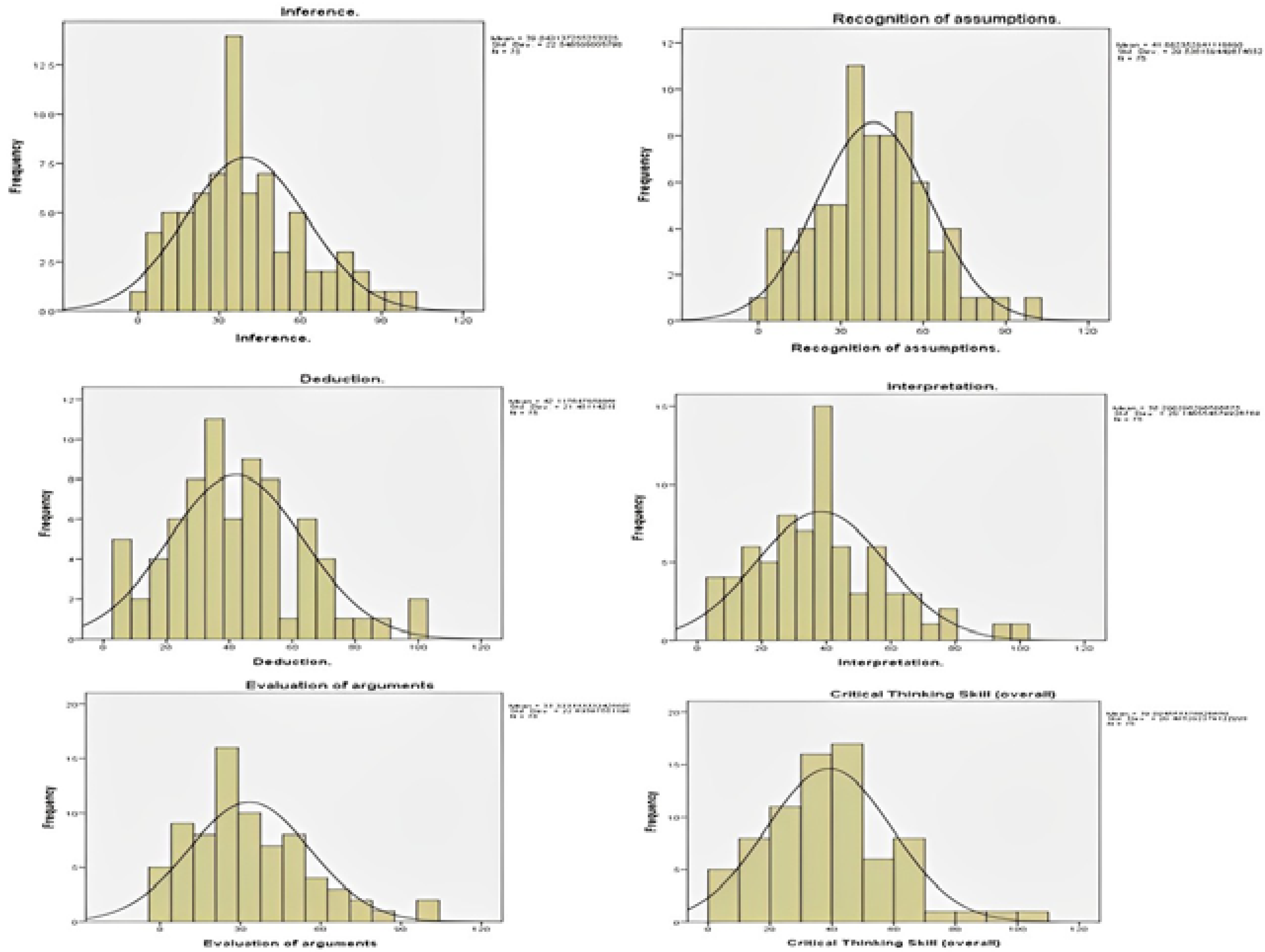
**Table 29.** *Normality test for study variables*

| SKILLS | EXPERIMENTAL GROUP | | CONTROL GROUP | |
|---|---|---|---|---|
| | **Kolmogorov-Smirnov** | **Shapiro-Wilk** | **Kolmogorov-Smirnov** | **Shapiro-Wilk** |
| Overall Critical Thinking Skill: | 0.075 (0.200) | 0.972 (0.095) | 0.104 (0.043) * | 0.957 (0.012) * |
| a. Inference | 0.140 (0.001) ** | 0.960 (0.018) * | 0.194 (0.000) ** | 0.891 (0.000) ** |
| b. Recognition of assumptions | 0.081 (0.200) | 0.984 (0.465) | 0.137 (0.001) ** | 0.964 (0.032) * |
| c. Deduction | 0.105 (0.040) * | 0.967 (0.049) * | 0.112 (0.020) ** | 0.968 (0.053) |
| d. Interpretation | 0.142 (0.001) ** | 0.958 (0.014) ** | 0.190 (0.000) ** | 0.941 (0.002) ** |
| e. Evaluation of arguments | 0.150 (0.000) ** | 0.937 (0.001) ** | 0.180 (0.000) ** | 0.941 (0.002) ** |

**Note:** ** *Test is significant at the 0.01 level.* * *Test is significant at the 0.05 level.*

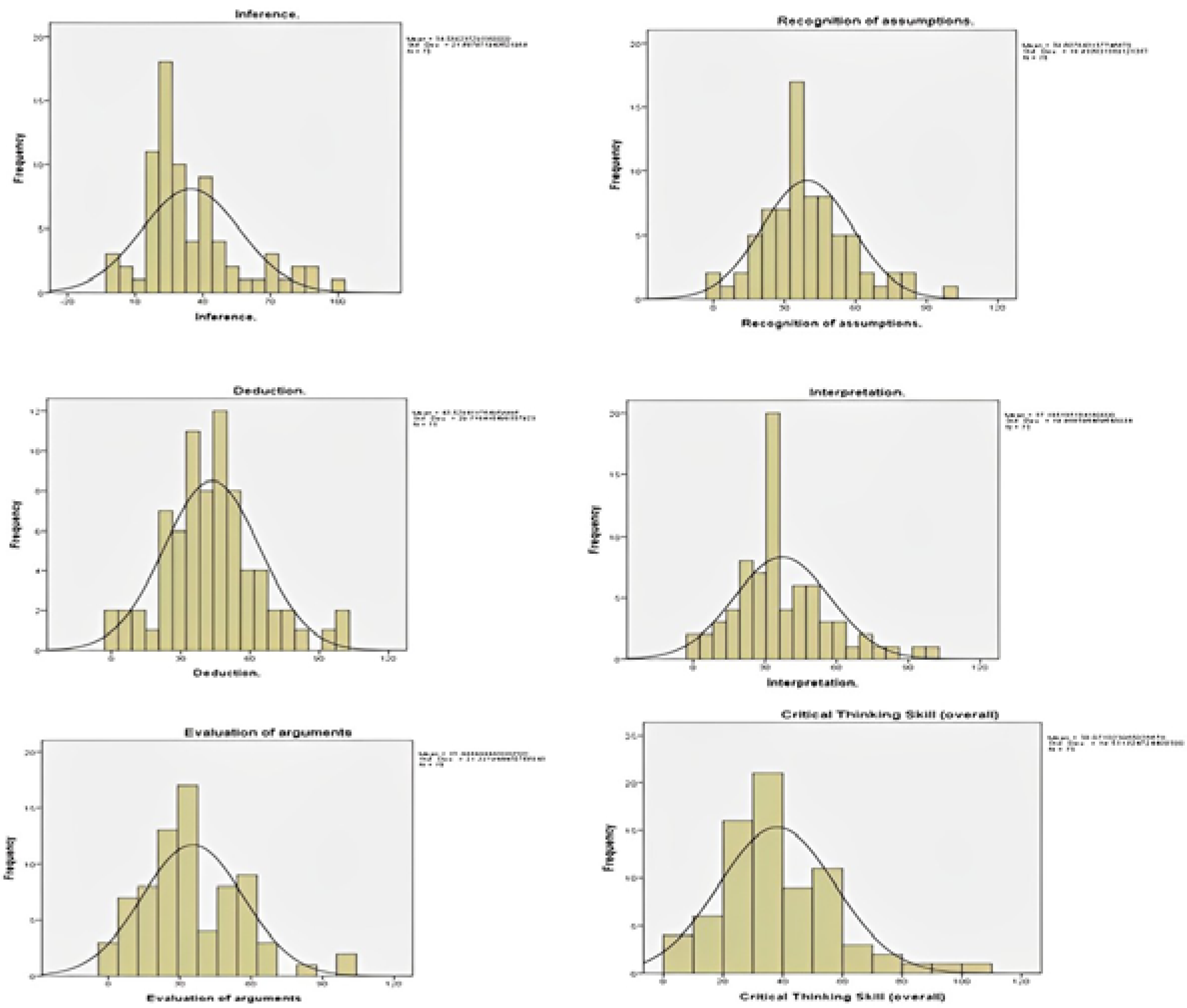
Figures 7 and 8 show a histogram that illustrates the frequency and variation in critical thinking skills displayed by participants in the experimental and control groups dimensions for interference, recognising assumptions, deduction, interpretation, and evaluating arguments. Using the dimensions of critical thinking skills, the overall critical thinking figure in this histogram provides an overview of the development of students' critical thinking skills. As can be seen from the figures, neither the experimental nor control groups exhibit normal distributions.

Figure 7. *Histogram of critical thinking skills for the experimental group*




Source: *Own elaboration.*

**Figure 8.** *Histogram of critical thinking skills for the control group*




**Source:** *Own elaboration*

The Levene test of statistical inference was used to determine whether the experimental and control groups possessed identical critical thinking skills. Based on the analysis (Table 28,) the obtained F value exceeds 0.05, indicating that there is no statistical significance. It applies to both the overall assessment of critical thinking skills and the subskills that comprise it, such as inference, recognising assumptions, deduction, interpretation, and evaluating arguments. Thus, both the experimental and control groups demonstrated consistency in their critical thinking abilities.

It is evident from the equality variance test (Tables 30 and 31) that the chi-square value exceeds the significance threshold of 0.05, thereby establishing a statistical benchmark. These results suggest that there is no significant association between the overall critical thinking skill and both the experimental and control groups, nor among the five subskills of critical thinking, namely inferences, assumption recognition, deduction, interpretation, and argument evaluation.

Table 30. *Levene test for variance*

| SKILLS | F | SIG | TEST DECISION | CONCLUSION |
|---|---|---|---|---|
| Overall Critical Thinking Skill: | 0.399 | 0.529 | $H_0$ is accepted | Homogeneous |
| a. Inference | 0.227 | 0.635 | $H_0$ is accepted | Homogeneous |
| b. Recognition of assumptions | 0.838 | 0.361 | $H_0$ is accepted | Homogeneous |
| c. Deduction | 0.345 | 0.558 | $H_0$ is accepted | Homogeneous |
| d. Interpretation | 0.010 | 0.919 | $H_0$ is accepted | Homogeneous |
| e. Evaluation of arguments | 0.231 | 0.631 | $H_0$ is accepted | Homogeneous |

Source: *Own elaboration*

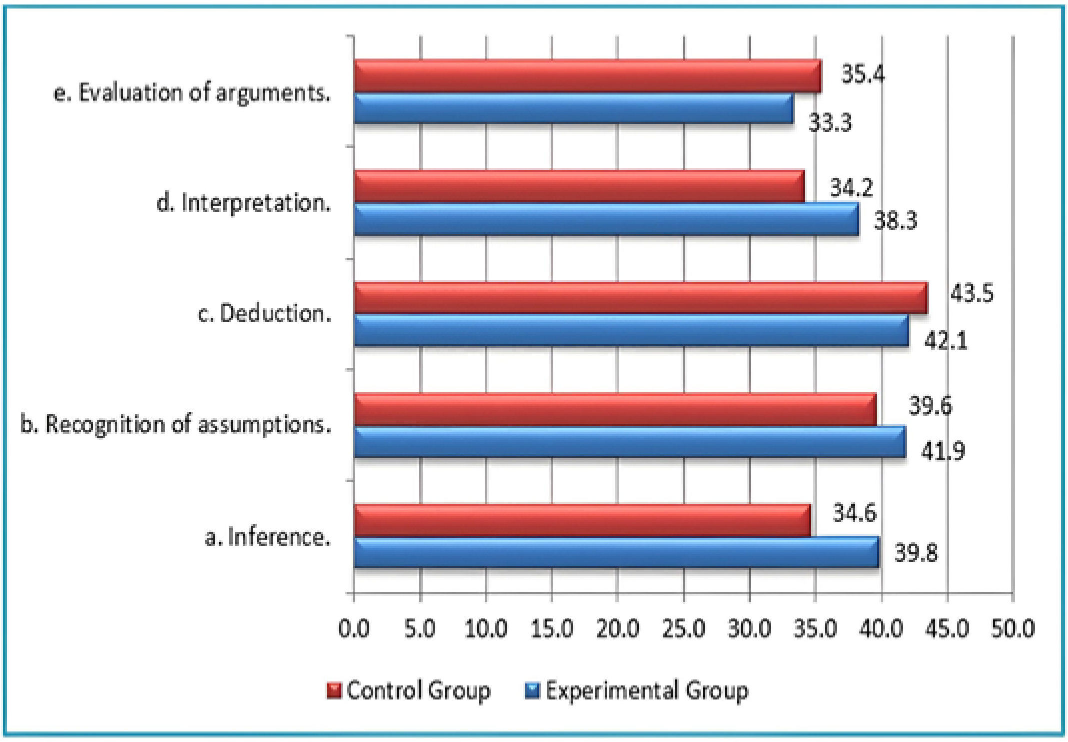
Table 31. *Chi-Square test for Independency*

| SKILLS | CHI-SQUARE | DF | SIG | TEST DECISION | CONCLUSION |
|---|---|---|---|---|---|
| Overall Critical Thinking Skill: | 137.333 | 118 | 0.108 | $H_0$ is accepted | Independency |
| a. Inference | 25.820 | 17 | 0.078 | $H_0$ is accepted | Independency |
| b. Recognition of assumptions | 9.2970 | 16 | 0.901 | $H_0$ is accepted | Independency |
| c. Deduction | 11.363 | 17 | 0.837 | $H_0$ is accepted | Independency |
| d. Interpretation | 21.263 | 17 | 0.215 | $H_0$ is accepted | Independency |
| e. Evaluation of arguments | 7.6160 | 11 | 0.747 | $H_0$ is accepted | Independency |

Source: *Own elaboration*

Figure 9 shows the comparison of critical thinking skills between the experimental and control groups. Based on the comparison of critical thinking skills between the experimental and control groups in Figure 10, the following conclusions can be drawn. In terms of evaluating arguments and deduction, the mean scores of the control group are higher than those of the experimental group. Interference, recognition of assumptions, and interpretation are higher in the experimental group.

Figure 9, *Comparison of critical thinking skills means between the experimental and control group*




Source: *Own elaboration*

In Table 32 the Mann-Whitney-Wilcoxon tests are used to compare the trends in a single variable between two independent groups. Using this test, we examined whether the average level of critical thinking skills test results in both sample groups is comparable, whether any differences are due to chance, or whether significant variations between the results of the two groups are substantial and supported by statistical evidence. It is determined that the Mann-Whitney Test has no statistical reference if the value of the statistical reference (Z) for the five substandard thinking skills (interference, recognition of assumptions, deduction, interpretation, and evaluation of arguments) is greater than 0.05 and ($p > 0.05$), which indicates that the zero assumption was accepted, and both groups received the same marks. In conclusion, the experimental and controlled groups show no differences in the statistical references either in the critical thinking skill as a whole or in the other substandard skills before the intervention which will result in both groups being applied to project-based learning (PBL).

Table 32. *Mann-Whitney-Wilcoxon test to compare the distribution between the control and experimental group*

| SKILLS | GROUPS | MEAN RANK | MANN-WHITNEY U | Z | ASYMP. SIG. |
|---|---|---|---|---|---|
| a. Inference | Experimental group | 81.83 | 2338 | -1.793 | 0.073 |
| | Control group | 69.17 | | | |
| b. Recognition of assumptions | Experimental group | 78.82 | 2563.5 | -0.941 | 0.347 |
| | Control group | 72.18 | | | |
| c. Deduction | Experimental group | 73.60 | 2670 | -0.538 | 0.590 |
| | Control group | 77.40 | | | |
| d. Interpretation | Experimental group | 77.43 | 2668 | -0.546 | 0.585 |
| | Control group | 73.57 | | | |
| e. Evaluation of arguments | Experimental group | 72.63 | 2597 | -0.817 | 0.414 |
| | Control group | 78.37 | | | |

Source: *Own elaboration.*

*7.8.2.2 Post-test results of Adaptation Watson and Glaser critical thinking instrument (experimental and control groups)*

Using the post-test, the experimental group was compared with the control group to determine whether the results of the critical thinking test were different after the experimental group received PBL instruction in STEM subjects while the control group received traditional instruction.

Following the PBL intervention (Table 33), the number of correct responses from students in both the experimental and control groups, as well as their performance on the theoretical and practical thinking skills tests, increased. As part of the theoretical questions, principles, assumptions, and implications of a given topic were tested to stimulate critical thinking and intellectual exploration in the students. As with the practical questions, the theoretical questions did not require the use of a calculator.

Table 33. *Results of the post-test (experimental and control group) critical thinking correct responses*

| QUESTIONS | EXPERIMENTAL GROUP | | CONTROL GROUP | |
|---|---|---|---|---|
| | Frequency | % | Frequency | % |
| **Theory** | | | | |
| Question (1) | 30 | 40 | 43 | 57.3 |
| Question (2) | 51 | 68 | 49 | 65.3 |
| Question (3) | 41 | 54.7 | 40 | 53.3 |
| Question (4) | 47 | 62.7 | 47 | 62.7 |
| Question (5) | 47 | 62.7 | 25 | 33.3 |
| Question (6) | 50 | 66.7 | 14 | 18.7 |
| Question (7) | 43 | 57.3 | 43 | 57.3 |
| Question (8) | 42 | 56 | 46 | 61.3 |
| Question (9) | 46 | 61.3 | 27 | 36 |
| Question (10) | 47 | 62.7 | 17 | 22.7 |
| Question (11) | 35 | 46.7 | 30 | 40 |
| Question (12) | 47 | 62.7 | 18 | 24 |
| **Practical** | | | | |
| Question (1) | 52 | 69.3 | 51 | 68 |
| Question (2) | 49 | 65.3 | 53 | 70.7 |
| Question (3) | 43 | 57.3 | 14 | 18.7 |
| Question (4) | 45 | 60 | 51 | 68 |
| Question (5) | 23 | 30.7 | 20 | 26.7 |
| Question (6) | 16 | 21.3 | 23 | 30.7 |
| Question (7) | 53 | 70.7 | 23 | 30.7 |
| Question (8) | 24 | 32 | 23 | 30.7 |
| Question (9) | 54 | 72 | 23 | 30.7 |
| Question (10) | 54 | 72 | 17 | 22.7 |
| Question (11) | 38 | 50.7 | 41 | 54.7 |
| Question (12) | 42 | 56 | 20 | 26.7 |
| Question (13) | 43 | 57.3 | 48 | 64 |

Source: *Own elaboration*

### *7.8.2.3 Differences between the experimental and control group post-test critical thinking score*

The experimental group and the control group differ significantly in their responses to the critical thinking questions at pre-test and post-test, as shown in Table 34. It shows the frequency and percentage of accurate responses from the experimental group following the PBL intervention. During the pre-test, the experimental group demonstrated lower scores on theoretical questions 2, 4, and 7, as well as practical questions 2, 4, 10, and 11. After the post-test, their scores exceeded those of the control group, who received traditional instruction.

**Table 34.** *Results indicating the differences in answers of control and experimental pre-and post-test critical thinking responses.*

| QUESTIONS | PRETEST | | | | INTERVENTION PHASE | POST-TEST | | | |
|---|---|---|---|---|---|---|---|---|---|
| | EXPERIMENTAL GROUP | | CONTROL GROUP | | | EXPERIMENTAL GROUP | | CONTROL GROUP | |
| | frequency | % | frequency | % | | frequency | % | frequency | % |
| **§ Theory part:** | | | | | | | | | |
| Question (1) | 24 | 32 | 23 | 30.7 | | 30 | 40 | 43 | 57.3 |
| Question (2) | 54 | 72 | 55 | 73.3 | | 51 | 68 | 49 | 65.3 |
| Question (3) | 46 | 61.3 | 44 | 58.7 | | 41 | 54.7 | 40 | 53.3 |
| Question (4) | 53 | 70.7 | 54 | 72 | | 47 | 62.7 | 47 | 62.7 |
| Question (5) | 24 | 32 | 25 | 33.3 | | 47 | 62.7 | 25 | 33.3 |
| Question (6) | 16 | 21.3 | 14 | 18.7 | | 50 | 66.7 | 14 | 18.7 |
| Question (7) | 56 | 74.7 | 55 | 73.3 | | 43 | 57.3 | 43 | 57.3 |
| Question (8) | 22 | 29.3 | 21 | 28 | | 42 | 56 | 46 | 61.3 |
| Question (9) | 29 | 38.7 | 27 | 36 | | 46 | 61.3 | 27 | 36 |
| Question (10) | 18 | 24 | 17 | 22.7 | | 47 | 62.7 | 17 | 22.7 |
| Question (11) | 46 | 61.3 | 21 | 28 | | 35 | 46.7 | 30 | 40 |
| Question (12) | 24 | 32 | 18 | 24 | | 47 | 62.7 | 18 | 24 |
| **§ Practical part:** | | | | | | | | | |
| Question (1) | 26 | 34.7 | 24 | 32 | | 52 | 669.3 | 51 | 668 |
| Question (2) | 25 | 333.3 | 55 | 73.3 | | 49 | 655.3 | 53 | 770.7 |
| Question (3) | 46 | 661.3 | 14 | 158.7 | | 43 | 557.3 | 14 | 118.7 |
| Question (4) | 47 | 662.7 | 51 | 668 | | 45 | 660 | 51 | 668 |
| Question (5) | 24 | 332 | 14 | 118.7 | | 23 | 330.7 | 20 | 226.7 |
| Question (6) | 17 | 222.7 | 17 | 222.7 | | 16 | 221.3 | 23 | 330.7 |
| Question (7) | 16 | 221.3 | 23 | 330.7 | | 53 | 770.7 | 23 | 330.7 |
| Question (8) | 47 | 622.7 | 23 | 330.7 | | 24 | 332 | 23 | 330.7 |
| Question (9) | 24 | 332 | 23 | 330.7 | | 54 | 772 | 23 | 330.7 |
| Question (10) | 15 | 220 | 17 | 222.7 | | 54 | 772 | 17 | 222.7 |
| Question (11) | 16 | 221.3 | 51 | 668 | | 38 | 570.7 | 41 | 554.7 |
| Question (12) | 24 | 332 | 20 | 226.7 | | 42 | 556 | 20 | 226.7 |
| Question (13) | 21 | 228 | 14 | 118.7 | | 43 | 557.3 | 48 | 664 |
| Average Mean | 30.4 | 440.532 | 28.8 | 3<br>338.412 | | 42.48 | 556.644 | 32.24 | 422.996 |

**Source:** *Own elaboration*

Table 35 shows the frequency and percentage of accurate responses from the experimental group following the PBL intervention. During the pre-test, the experimental group demonstrated lower scores on theoretical questions 2 and 7, as well as practical questions 2, 4, 10 and 11. After the post-test, their scores exceeded those of the control group, who received traditional instruction. See Figure 10 and Figure 11.

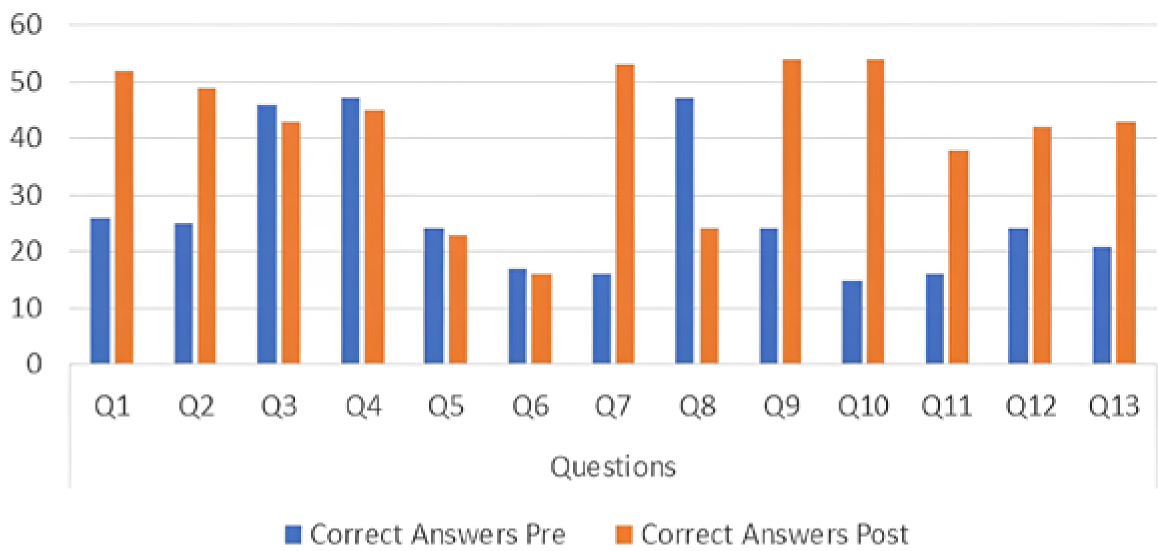
**Table 35.** *Experimental group pre-test and post-test correct answers*

| THEORETICAL PART | QUESTIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Experimental Group | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 |
| Correct Answers Pre | 24 | 54 | 46 | 53 | 24 | 16 | 56 | 22 | 29 | 18 | 46 | 24 |
| Correct Answers Post | 30 | 51 | 41 | 47 | 47 | 50 | 43 | 42 | 46 | 47 | 35 | 47 |

| PRACTICAL PART | QUESTIONS | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Experimental Group | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 | Q13 |
| Correct Answers Pre | 26 | 25 | 46 | 47 | 24 | 17 | 16 | 47 | 24 | 15 | 16 | 24 | 21 |
| Correct Answers Post | 52 | 49 | 43 | 45 | 23 | 16 | 53 | 24 | 54 | 54 | 38 | 42 | 43 |

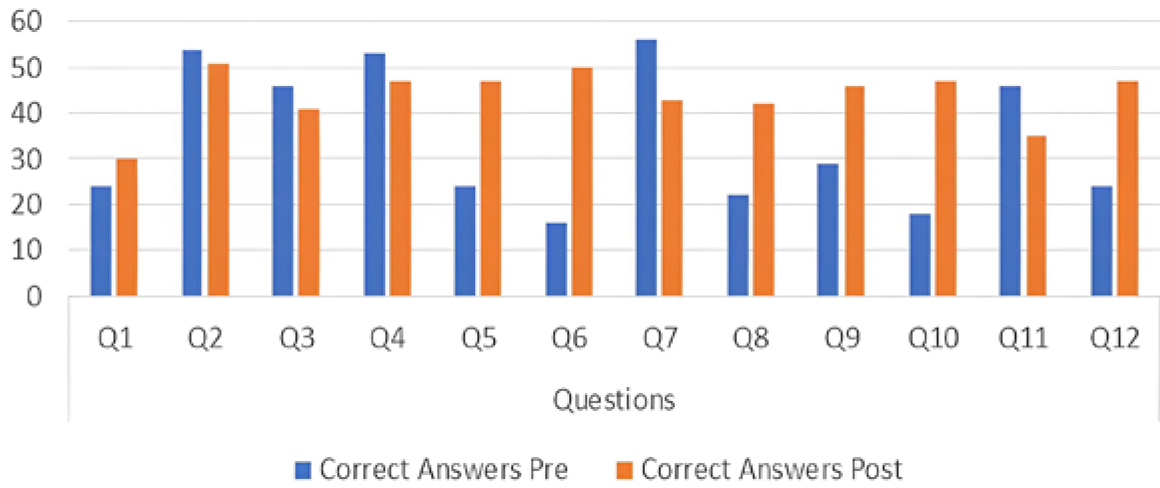
**Source:** *Own elaboration*

**Figure 10.** *Experimental group pre-test practical correct answers*




**Source:** *Own elaboration*

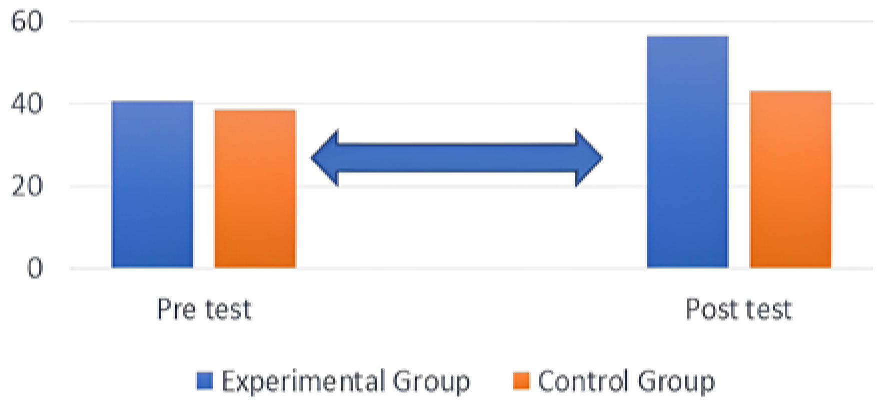
Figure 11. *Experimental group post-test theoretical correct answers*




Source: *Own elaboration*

Figure 12 provides an overview of the results obtained by both experimental and control groups during the pre-test and post-test phases. By comparing the outcomes of the experimental group with those of the control group, which was not subjected to the same intervention, Figure 13 allows us to evaluate the effects of the intervention on the experimental group.

Figure 12. *Results of experimental and control group questions during the pre-test and post-test*




Source: *Own elaboration.*

Table 36 compares the mean values between the pre-test and post-test. Table 36 shows that the mean scores of the post-test for the experimental group that participated in project-based learning significantly increased statistically. Average scores have increased by 17.6%. It appears that students have improved in their performance, moving from the level of a challenged to that of a beginner thinker. According to Elder and Paul (2010), in Chapter 3, a beginner thinker is defined as an individual who is pursuing the development and refining of their critical thinking skills. In addition, they have a desire to comprehend the methods through which these skills can be enhanced and modified. Challenged thinkers, meanwhile, are aware of their cognitive limitations but have difficulty identifying and acknowledging them.

**Table 36.** *Mean comparison of pre-test and post-test results*

| GROUPS | TEST | OBS. | MEAN | STD. DEV. | MIN | MAX | CATEGORY | MEAN DIFFERENCE IN POST-TEST |
|---|---|---|---|---|---|---|---|---|
| **Experimental group** | **Pretest** | 75 | 39.0946 | 20.485 | 3.4641 | 100 | Challenged | 17.6052 |
| | **Post-test** | 75 | 56.6998 | 24.145 | 7.4837 | 100 | Beginning | |
| **Control group** | **Pretest** | 75 | 38.0710 | 19.511 | 0 | 100 | Challenged | 3.7647 |
| | **Post-test** | 75 | 41.8357 | 18.309 | 0 | 100 | Beginning | |

Table 337 shows the students' critical thinking skills can be measured using the following N-Gain criteria: high > 0.70; moderate 0.3 - 0.70; low <0.30.

**Table 37.** *The N-gain criteria for the improvement of students' critical thinking skills*

| PERCENTAGE OF N-GAIN (%) | CRITERIA OF STEM IMPROVEMENT |
|---|---|
| | High |
| | Medium |
| | Low |

**Source:** *Own elaboration*

The comparison of Table 38 reveals that the experimental group achieved a higher N-gain score of critical thinking than the controlled group.

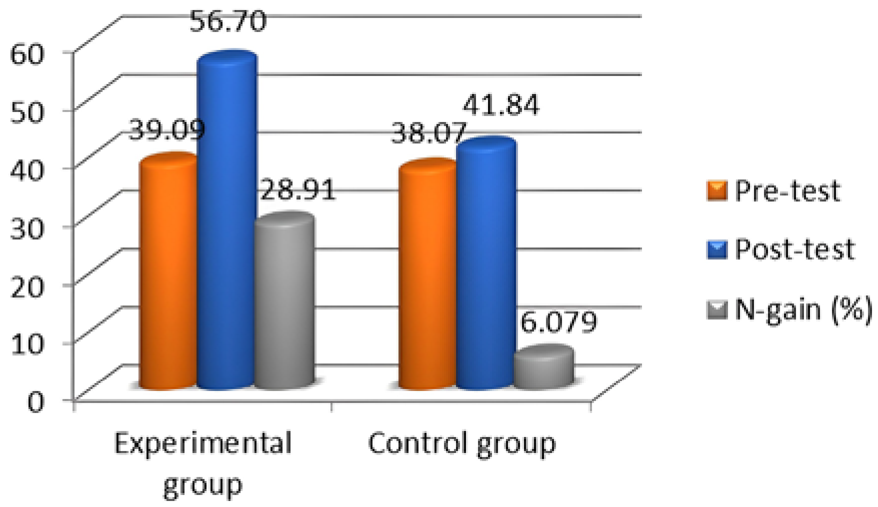
**Table 38.** *The Result of N-gain score of critical thinking skill*

| GROUPS | N-GAIN AVERAGE SCORE | CATEGORY |
|---|---|---|
| Experimental | 28.91 | Low |
| Control | 6.079 | Low |

**Source:** *Own elaboration*

Figure 13 illustrates a comparison of the pre-test and post-test scores and their N-gain scores for the general critical thinking questions based on the pre-test and post-test results.

Figure 13. *Results comparison of pre/post-test and N-gain for overall critical thinking between pre-test and post-test questions*




Source: *Own elaboration.*

Based on the findings shown in Table 39, it can be observed that the experimental group had better results in comparison to the control group across five distinct subskills of the critical thinking test. The experimental group received instruction in science, technology, engineering, and mathematics (STEM) through the implementation of PBL, while the control group was taught using traditional teaching methods in the same subjects.

As illustrated in Table 39, both the experimental and controlled groups displayed a beginning level of critical thinking in relation to the five sub-skills of critical thinking. However, it is important to highlight that the controlled group remains within the classification of those who face difficulties in making inferences and evaluating arguments. As a result, a clear differentiation arises between the experimental and controlled groups. The experimental group exhibits a performance level that closely approximates that of a beginning thinker in the five critical thinking subskills, whereas the performance level of the controlled group remains confined to the domain of struggling with critical thinking.

Table 39. *Comparison of pre-test and post-test results for the five subskills of critical thinking*

| SKILLS | GROUPS | | PRE-TEST | | POST-TEST | | MEAN DIFFERENCE IN POST-TEST |
|---|---|---|---|---|---|---|---|
| | | Obs. | Mean | Std. Dev. | Mean | Std. Dev. | |
| Inference | Experimental | 75 | 39.8431 | 22.547 | 60.3137 | 26.661 | 20.471 |
| | Control | 75 | 34.5882 | 21.688 | 40.5490 | 19.571 | 5.9608 |
| Recognition of assumptions | Experimental | 75 | 41.8824 | 20.536 | 58.1961 | 22.896 | 16.314 |
| | Control | 75 | 39.6078 | 18.934 | 42.5882 | 17.801 | 2.9804 |
| Deduction | Experimental | 75 | 42.1176 | 21.451 | 57.8039 | 23.911 | 15.686 |
| | Control | 75 | 43.5294 | 20.718 | 45.4118 | 19.379 | 1.8824 |
| Interpretation | Experimental | 75 | 38.2963 | 20.147 | 54.0741 | 23.381 | 15.778 |
| | Control | 75 | 34.1852 | 19.989 | 42.0741 | 19.227 | 7.8889 |
| Evaluation of arguments | Experimental | 75 | 33.3333 | 22.636 | 53.1111 | 26.978 | 19.778 |
| | Control | 75 | 35.4444 | 21.228 | 38.5556 | 20.494 | 3.1112 |

Source: *Own elaboration.*

Using the Wilcoxon and Mann-Whitney tests, we further evaluated the effectiveness of PBL in enhancing critical thinking skills.

In Table 40, the Wilcoxon Signed Ranks Test is used to evaluate the significance of differences between pre-test and post-test measurements within an experimental group. Table 40 shows a statistical Z value of (-4.005) with an expected value of 0.05 for the experimental and control groups. Using the Wilcoxon Test, it appears there is indeed a difference in critical thinking skills between the pre- and post-test results. This finding suggests that it is reasonable to accept the alternative assumption that statistically significant differences exist between the pre- and post-test results for critical thinking skills. It is evident from the significant number of positive rankings (39.16%) compared to negative ranks (34.58%) that the discrepancy favours the post-test. This implies that the scores of critical thinking in the post-test are notably higher than those in the pre-test.

For the five subskills of critical thinking measured by the Wilcoxon Test, the statistical value of Z ranges from -3.841 to -4.340, with an expected value lower than 0.005. Using the data presented in Table 39, it appears that PBL has resulted in positive and substantial changes at the level of students' critical thinking skills. It has become evident that PBL impacts student learning significantly, particularly when it comes to their ability to think critically.

**Table 40.** *Wilcoxon Signed Ranks Test for differences between pre-test and post-test for experimental group*

| SKILLS | GROUPS | MEAN RANK | Z | ASYMP. SIG. |
|---|---|---|---|---|
| Critical Thinking Skill: | Negative Ranks | 34.58 | -4.055 | 0.000** |
| | Positive Ranks | 39.16 | | |
| Inference | Negative Ranks | 30.18 | -4.340 | 0.000** |
| | Positive Ranks | 40.85 | | |
| Recognition of assumptions | Negative Ranks | 32.58 | -3.841 | 0.000** |
| | Positive Ranks | 36.51 | | |
| Deduction | Negative Ranks | 35.37 | -3.604 | 0.000** |
| | Positive Ranks | 36.91 | | |
| Interpretation | Negative Ranks | 31.45 | -3.847 | 0.000** |
| | Positive Ranks | 38.44 | | |
| Evaluation of arguments | Negative Ranks | 36.21 | -4.045 | 0.000** |
| | Positive Ranks | 37.24 | | |

**Source:** *Own elaboration*

The Mann-Whitney Test is used in Table 41 to identify the differences between the experimental and control groups. Table 36 shows the results of the Mann-Whitney test, which illustrates the impact of variation on the rank averages between the experimental and control groups. Therefore, the experimental group consistently performed better in each of the subskills than the control group.

**Table 41.** *Mann-Whitney test*

| Skills | Groups | Mean Rank | Mann-Whitney U | Z | Asymp. Sig. |
|---|---|---|---|---|---|
| a. Inference | Experimental group | 91.55 | 1608.5 | -4.539 | 0.000** |
| | Control group | 59.45 | | | |
| b. Recognition of assumptions | Experimental group | 92.57 | 1532.5 | -4.829 | 0.000** |
| | Control group | 58.43 | | | |
| c. Deduction | Experimental group | 88.67 | 1824.5 | -3.725 | 0.000** |
| | Control group | 62.33 | | | |
| d. Interpretation | Experimental group | 88.72 | 1821.0 | -3.738 | 0.000** |
| | Control group | 62.28 | | | |
| e. Evaluation of arguments | Experimental group | 89.65 | 1751.0 | -4.010 | 0.000** |
| | Control group | 61.35 | | | |

**Source:** *Own elaboration*

PBL's effect on student learning is measured using the effect size concept, which quantifies the extent of the PBL intervention. Generally, a larger effect size indicates a stronger relationship between the variables being studied, thereby indicating whether PBL has a small, moderate, or large effect on students' critical thinking abilities. Cohen's model (Sullivan & Feinn, 2012) was used to calculate the effect size. Using this model, it is possible to compare two averages, namely those of the experimental and control groups. It is possible to determine the effect size by subtracting one average from the other (M1 - M2) and dividing the result by the standard deviation of the participants.

$$\text{Effect size} = \frac{\text{Mean of experimental group - Mean of control group}}{\text{Standard deviation}}$$

Table 42 explores the effectiveness of the PBL in enhancing critical thinking skills and shows that PBL reinforced critical thinking skills among 11$^{th}$-grade boys attending a vocational high school. A significant increase in critical thinking skills was observed, measured at 0.688, exceeding the threshold of 0.6, indicating that PBL had a strong influence on enhancing critical thinking abilities in this group.

**Table 42.** *The effect size criteria*

| THRESHOLD | CATEGORY |
|---|---|
| 0.0 - 0.2 | Small |
| 0.3 - 0.5 | Medium |
| 0.6 –0.8 | Large |

**Source:** *Own elaboration*

In Table 43, the effect size can be considered statistically significant if it falls within a confidence interval (0.3642 - 1.0233). The five critical thinking skills (interference, recognition of assumptions, deduction, interpretation, and evaluation of arguments) effect sizes range from (0.651 - 0.756), indicating that the innovation has a significant impact on reinforcing these skills, except for the interpretation skill, which has an effect size of (0.391). Accordingly, considering that these effects have statistical significance at 1% or 5%, this study has achieved a medium average effect size in reinforcing the critical thinking skills of students.

**Table 43.** *The effect size for critical thinking skills*

| SKILLS | EFFECT SIZE (COHEN'S D) | CONFIDENCE INTERVAL (CI 95%) | P-VALUE | CATEGORY |
|---|---|---|---|---|
| a. Inference | 0.653 | 0.5111 - 1.1792 | 0.000** | Large |
| b. Recognition of assumptions | 0.672 | 0.4296 - 1.0925 | 0.001** | large |
| c. Deduction | 0.651 | 0.2429 - 0.8959 | 0.014* | large |
| d. Interpretation | 0.391 | 0.2343 - 0.8869 | 0.022* | medium |
| e. Evaluation of arguments | 0.756 | 0.2802 - 0.9349 | 0.013* | large |

***Note:*** *** refer to significant at the 0.01 level, * refer to significant at the 0.05 level.*

This study confirms that there is a statistically significant difference in critical thinking between experimental and control groups after PBL instruction in STEM. The results indicate that PBL instruction significantly enhances critical thinking when compared to traditional instruction.

Table 44 and Table 45 show the differences in the Cronbach alpha results of the control group and the experimental group before and after the intervention. This is because the pre-test provided a baseline understanding of the students' initial critical thinking skills related to STEM subjects. The test serves as a starting point and measures any discrepancies among students before introducing PBL. By performing Cronbach's alpha analysis on the pretest, we were able to ensure the reliability and consistency of the test items used to assess critical thinking skills in both non-piloted student groups. Comparing participants' critical thinking skills before and after the intervention helped assess the success of the PBL approach. Providing empirical evidence of improvements or changes in critical thinking abilities, this comparison provides valuable insight into the impact of PBL on enhancing critical thinking skills in the actual sample.

**Table 44.** *Pre- and post-test Cronbach alpha of the control group before and after intervention*

| SKILLS | NO OF ITEMS | CRONBACH'S ALPHA | |
|---|---|---|---|
| | | **Before Intervention** | **After Intervention** |
| *Inference* | 17 | 0.795 | 0.712 |
| *Recognition of assumptions* | 17 | 0.716 | 0.633 |
| *Deduction* | 17 | 0.767 | 0.701 |
| *Interpretation* | 18 | 0.770 | 0.717 |
| *Evaluation of arguments* | 12 | 0.708 | 0.650 |
| *Overall Critical Thinking Skill* | **25** | **0.813** | **0.761** |

**Source:** *Own elaboration*

**Table 45.** *Pre- and post-test Cronbach alpha of the experimental groups before and after the intervention*

| SKILLS | NO OF ITEMS | CRONBACH'S ALPHA | |
|---|---|---|---|
| | | **Before Intervention** | **After Intervention** |
| *Inference* | 17 | 0.796 | 0.857 |
| *Recognition of assumptions* | 17 | 0.747 | 0.786 |
| *Deduction* | 17 | 0.779 | 0.805 |
| *Interpretation* | 18 | 0.772 | 0.807 |
| *Evaluation of arguments* | 12 | 0.726 | 0.806 |
| *Overall Critical Thinking Skill* | **25** | **0.835** | **0.864** |

**Source:** *Own elaboration*

## 7.9. General discussion and conclusion of Study 1

Based on the discussions and conclusions drawn from the two instruments used, in this section we will first offer general observations and conclusions derived from the STEM Semantics Survey. We then discuss and conclude the Watson and Glaser Critical Thinking Test, presenting a comprehensive analysis for both measures.

### 7.9.1. Discussion and conclusion: STEM Semantics Survey

As part of our discussion of the STEM Semantics Survey, we examined the results of the control group, which was exposed to traditional instructional methods after the PBL intervention. We compare them with the results of the experimental group, which received instruction using project-based learning (PBL). With the aim of investigating the impact of PBL on students' interest in STEM. A Relative Importance Index (RII) was used to evaluate students' interest in STEM subjects. The RII holds significant value in that it provides information about the factors within the realms of science, technology, engineering, and mathematics that are most influential on students' interest in these fields. Students' preferences within the STEM subjects may also be better understood using the RII.

It is evident from Table 24 RII that the control group encountered challenges in the field of mathematics, whereas the experimental group had a positive experience, finding mathematics to be enjoyable. As indicated by the RII score of 91.2%, the experimental group may be inclined to pursue careers in mathematics. The control group exhibited the lowest RII regarding science and its relevance to their future careers (Table 25). Compared to the control group, individuals in the experimental group were more inclined to consider pursuing a career in science. As shown in Table 25, the experimental group demonstrated the significance of STEM disciplines and PBL for their future careers. An RII of 85.8% was demonstrated by the experimental group, which indicates a high level of proficiency in the ability to work collaboratively.

In determining how Project-Based Learning has stimulated an inclination towards STEM disciplines, the STEM Semantics Survey has successfully achieved its objective. The STEM Semantics Survey found that pedagogical methods, PBL, and traditional instruction have a significant impact on students' interest in STEM disciplines. One of the primary conclusions derived from the survey is that PBL appears to exert a notable and favourable impact on the experimental group's inclination toward STEM subjects. Conversely, the control group, which was exposed to the traditional instructional method, displayed a diminished degree of interest in pursuing careers in STEM fields.

As a result of the above findings, it's necessary to employ novel pedagogical approaches, such as project-based learning, to cultivate students' interest in STEM fields. Involving students in PBL enables them to gain a deeper understanding of STEM subjects as well as establish connections between these concepts and their practical application in real-life scenarios, thereby increasing their interest and significance in STEM subjects. Thus, the STEM Semantics Survey indicates that project-based learning has a substantial impact on STEM interest observed in the experimental group.

The findings emphasize the strong link between engineering and technology, especially when we look at how the controlled group rated the importance of 21st-century skills at an average level of 61.6% to 70.6%. We were able to see a remarkable improvement in the 21st century skills of the experimental group when we introduced PBL. The mean value increased from 75% to 86.4%. Prioritising tasks at 86.4%, closely followed by the ability to collaborate effectively with peers of different backgrounds at 85.8%. At 85.6%, students demonstrated confidence that they would meet high-quality standards. Also, the ability to manage time while respecting others at 84.6%, shows its significance. Furthermore, 82.4% of students were considered capable of handling tough situations and making changes. While 80.8% had their educational goals well regulated. In addition, 79.2% felt confident in inspiring others to hit their goals, while 75% were confident in guiding others effectively.

### 7.9.2. Discussion and conclusion: Watson and Glaser Critical Thinking Test

Watson and Glaser Critical Thinking Test results have provided valuable insights into the development of critical thinking skills within the context of this research. The results of the study, which were particularly illuminating, revealed substantial improvements among the experimental group participants. By demonstrating this significant progress, they were able to reach the beginning stage of critical thinking proficiency. However, the control group exhibited traits and behaviours that were more closely aligned with those of a challenged thinker, emphasising the crucial role played by project-based learning (PBL).

In reviewing the data, it became apparent that the PBL intervention had a significant impact on different aspects of critical thinking. There was a significant improvement in critical thinking skills among participants in the experimental group. These improvements were evident in the areas of interference detection, assumption recognition, interpretation of complex information, logical deduction, and evaluative analysis of arguments. The PBL approach provided compelling evidence of its effectiveness in fostering the development of critical thinking in each of these domains.

Comparatively, the control group, which did not benefit from the PBL intervention, did not exhibit such a pronounced improvement in critical thinking abilities. Considering the disparity between the two groups, project-based learning is a proven technique for enhancing critical thinking skills by incorporating it into educational strategies.

This study demonstrates that PBL can be an effective strategy for enhancing critical thinking skills. Clearly, as evidenced by the results, PBL has the capacity to elevate individuals within the realm of critical thinking from the status of a challenged thinker to that of a beginning thinker. The results of Watson and Glaser's Critical Thinking Test demonstrate that project-based learning in education is an effective tool for cultivating sharper, more discerning, and more competent critical thinkers.

# CHAPTER 8.
# STUDY 2: EFFECTS OF PBL ON EFFECTIVE LEARNING FOR STUDENTS IN STEM DISCIPLINES: THE PERSPECTIVE OF TEACHERS AND STUDENTS

Chapter 8 examines the results of qualitative study, providing a rich and insightful analysis of the data collected and analysed throughout the study. A thorough analysis of the key themes, patterns, and discoveries arising from the qualitative study process can be found within this key chapter. An overview of the study methodology is provided in the first section of the chapter, providing an overview of the study design, data collection methods, and criteria for selecting participants.

## 8.1. **Objective and research question**

The objective of Study 2 is to explore if PBL can create effective learning for students in STEM disciplines from the perspective of teachers and students. For this study, we attempted to answer the following research question: *"How can a Project-Based Learning (PBL) promote effective learning"?*

## 8.2. **Research design**

According to Salgado (2007), an action research design seeks to solve everyday problems and resolve concrete practices. The pillars on which this type of design is based are:

a) Participants who are experiencing a problem are best able to address it in a naturalistic setting.

b) The behaviour of these people is strongly influenced by the natural environment in which they find themselves.

c) Qualitative methodology is best suited to the study of naturalistic settings.

The essential phases of these designs are: Observe, Think and Act. These phases are cyclical, but in our case only the first two are considered, since the third phase will be for the educational administrations to make decisions based on the results obtained.

## 8.3. Participants

Purposive sampling was used to conduct the interviews, an approach well established in qualitative research (Given, 2008; Palinkas et al., 2015). We initially recruited six male STEM teachers and 10 $11^{th}$-grade students. Despite this, the final sample size was reduced to four teachers. Unfortunately, only four teachers and three 11th-grade students were able to be interviewed during COVID-19. Despite the relatively small sample size, we are confident that the insights derived from our interviews will contribute to the existing body of knowledge in a substantial and meaningful manner. Smaller sample sizes are often used in qualitative research, and sometimes even one participant may be sufficient (Boddy, 2017).

## 8.4. Instruments

We conducted structured interviews with the students and teachers to assess the effectiveness of STEM PBL education in developing critical thinking skills at a UAE public applied technology vocational high school. It was important to formulate the interview questions so that they would assist in establishing relationships and eliciting meaning from both students and teachers. Consequently, it was imperative that the interview questions yield insights regarding individuals' perspectives regarding project-based learning (PBL) and its impact on critical thinking.

It was essential that the questions be formulated in a way that allowed both students and teachers to establish connections and extract meaning from their assignments. Therefore, it was essential that the interview questions would provide us with feedback on perceptions of PBL and how it enhanced critical thinking, as well as recommendations for curricular and structural teaching methods that would facilitate the development of critical thinking skills.

### 8.4.1. Student interview questions

The following questions were presented to the students:

a) Identify the materials that will be used to construct your snail car.
b) What is the need for a snail car in the real world?
c) What do you think of building a snail car?
d) How would you design your snail car if you had a different design in mind than the one described in the instruction set?

### 8.4.2. Teacher interview questions

The following questions were asked of teachers:

a) Did you find a need for a snail car in the real world?
b) How did you feel about the STEM PBL experiment?
c) Was the snail car successful?
d) What did you learn during the STEM PBL experiment?
e) Did you consider the STEM intervention successful?
f) Which factors contributed to the success of the intervention?
g) Did you notice differences between students in the experimental and students in the control group?
h) Could you identify any challenges, and how did the students adapt to such challenges?
i) Did you find that students developed their critical thinking skills during the intervention?
j) In your opinion, is project-based learning effective in a STEM curriculum?
k) In your opinion, did the intervention have a clear focus; a real-life context that gave the students freedom to think for themselves; practical and interactive aspects; and a good balance across all STEM subjects?
l) Did the intervention contribute to understanding how students think, thus improving teaching and learning, and is there evidence for the effectiveness of the intervention?

## 8.5. **Procedures and ethics procedure**

Structured interviews were conducted with a small number of participants to obtain data. Standardised questions were designed to evaluate participant responses. Following the successful completion of the snail car construction, referred to in Chapter 6, we conducted interviews with the participants to better understand their critical thinking capabilities. Furthermore, interviews were conducted with teachers who received training in STEM education, as outlined in Chapter 6. These teachers were actively engaged in instructing STEM subjects, employing both traditional teaching methods and PBL instruction. The Zoom platform was found to be effective in facilitating the interview process. Two weeks of interviews were conducted in November 2020. Due to time constraints imposed by Zoom, which is only applicable for the free version, interviews were limited to a maximum of 20 minutes. All of the interviews were recorded in MP3 format. For the transcription of the audio recordings, we used *Transcribe*, a text editing software program developed by Wreally (n.d.). This software program includes an audio player and a text editor. With this feature, users are able to listen to interviews in real time and translate them word-for-word. As part of this feature, the user has the option of temporarily pausing the interview and replaying it at a later time, as necessary during transcription.

The ethical procedure followed was specified in the previous chapter. In this study, the same ethical issues referred to above are considered.

## 8.6. **Data analysis**

Three phases were followed for the analysis of the data: 1) Reading of the information obtained; 2) Coding of the data; 3) Interpretation of the data. The qualitative data in this study was analysed using MAXQDA, which offers the capability of analysing a wide range of data types, including video, audio, websites, tweets, discussion groups, focus groups, and surveys (MAXQDA, 2022). A thorough review of individual cases is the first step in the MAXQDA data analysis process. This analytical process refers to the categorization of text parts as thematic categories. Consequently, the transcribed interviews were used to clarify significant topics based on the transcriptions. During the coding phase, text segments belonging to the same category are compared side by side in preparation for subsequent data analysis. Comparative analysis is used to examine themes in this study, employing contrasting comparisons to reveal common characteristics among individuals, unique properties of specific cases, and their relationship to one another. As Kuckartz (2014) points out, coding and retrieval approaches require a considerable amount of time and effort on the part of the researchers, despite their apparent simplicity. By utilizing MAXQDA codes, we identified multiple themes. Some responses were transcribed verbatim.

### 8.6.1. Analysis of the data from student interviews

Data of the students' interviews that follow provide insights into how PBL building a snail car prototype and how it can be used in the real world has changed their perspective of PBL. Data was first coded, and a summary of the themes identified during the coding process is presented in Table 46. These themes include teamwork, critical thinking, problem-solving, and project-based learning. In this table, there are two columns that contain information obtained from personal interviews with students, which is intended for analysis purposes. In the first column, of Table 46, the coding or themes associated with different portions of the interview data are presented. Codes are generated based on the interpretation of responses and serve as representations of a variety of themes. In the second column, we present the frequency counts for each code. In view of the provided counts, it is apparent that interview responses have been assigned a specific code or theme more than once.

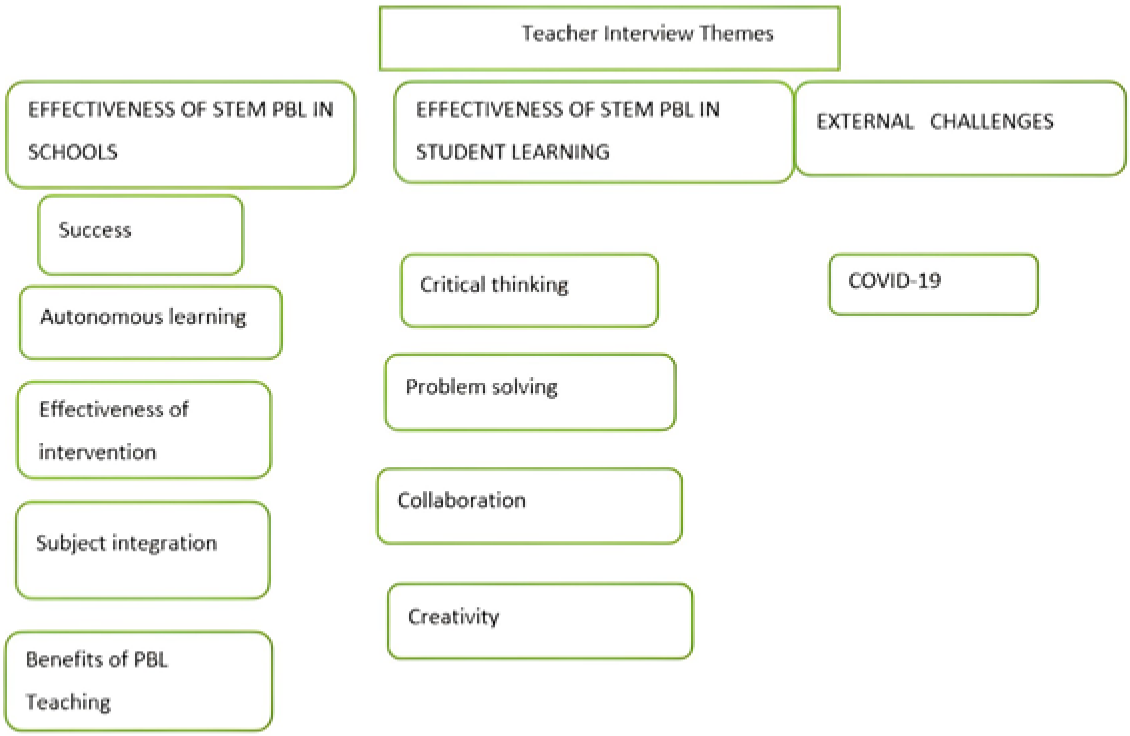
**Table 46.** *Student interview themes*

| CODE SYSTEM | FREQUENCY |
|---|---|
| Code System | 14 |
| Teamwork | 2 |
| Critical thinking | 5 |
| Problem solving | 3 |
| Project-Based Learning | 4 |

### 8.6.2. Analysis of the data from teacher interviews

During the interview, we asked a series of open-ended questions regarding the potential benefits of STEM education for the development of critical thinking skills. Additionally, we encouraged teachers to share their best practices during the STEM experiment (see Appendix 22). The questions put to teachers revolved around three themes: effectiveness of STEM PBL in school, effectiveness of STEM PBL in student learning and external challenges. The content of these themes emerged during the analysis of the interviews. Figure 14 is an overview of the key themes identified during the interviews with teachers.

Figure 14. *Teacher interview themes*




Source: *Own elaboration.*

## 8.7. **Results**

In this section, we discuss the results of the interviews with students and teachers conducted in Study 2.

### 8.7.1. Student interview themes

Using the codes shown in Table 42, the following themes emerged, such as critical thinking, problem-solving, Project-Based Learning (PBL), and teamwork.

*Theme 1: Critical thinking*

The implementation of hands-on projects facilitates the development of critical thinking, collaboration, and creativity among students. It was unanimously agreed by the students that their mindset had completely changed. In interviews with students, they expressed that they enjoyed building the snail car since it requires creativity as well as critical thinking, which are both essential for all competencies. Students 1 reported *"we focus on output, idea, and workout*. This implies that, in order to acquire an in-depth knowledge of how to construct the snail car, the student must consider multiple perspectives and investigate different points of view. Student 3 stated that his group had to brainstorm ideas, "*we researched how snails move, then built a snail car using engineering principles to mimic the snail's movement" We built a functional snail car prototype in the end".*

*Theme 2: Problem solving*

Concerning problem solving, students stated that they enjoyed the snail car project and could overcome a range of obstacles in the fields of science, technology, engineering, and mathematics. Student 1 focused on constantly evaluating the snail car's functionalities and improvements. Student 2 also talked about testing the snail car "*there were some construction challenges and our group had to make chances to make the snail car more efficient".* Student 1 focussed on constantly evaluating the progress such as "*functionality* "and how to make "*modifications"* to improve the snail car. Student 2 also talked about testing the snail car "*there were some construction challenges and our group had to make chances to make the snail car more efficient".*

*Theme 3: Project-Based Learning*

In PBL, the emphasis is shifted from teacher-centred instruction to student-centred learning, which promotes active engagement and fosters a deeper understanding of the content. The students agree that the directions were clear and required minimal input. This means that the students developed the ability to work independently, with the teacher serving as a facilitator. Students mentioned the experience and knowledge that they had gained during the STEM PBL experiment. Student one answered that STEM PBL real-life application *"helps you with your education, and you get to do things you wouldn't normally get to do. STEM is fun for me. I don't get to do that every day. I learned to convert all knowledge with different subjects into a practical ordinated application via working in teamwork and building a prototype to achieve the required objectives."* In PBL, students are engaged in an active, immersive learning environment, promoting critical thinking, problem-solving skills, and practical application of knowledge. According to Student 1,*"I am capable of making connections outside of my classroom, and the experiment connected me to real-world problems."* Student 3 backed up this claim by saying *"protect the environment*" and the environmentally friendly components they utilised to build the snail car. Students were particularly interested in how the snail car will no longer emit carbon monoxide and hazardous gases from its exhaust into the atmosphere as confirmed by student 2 "*our car is without sound on the road'* and *"clean material*". *I felt like an engineer when I was building the snail car with my friends and we to protect the environment.* The students recognized the importance of having a snail car. They confirmed its relevance *"in the real world for example mines detector robot, ad-*

*vance mechanical gearbox and advance electrical/electronic circuits* (Student 3). Another comment was about the materials "*most of the material provided were more than enough to come up with different ideas for the project"* (Student 1). The STEM PBL project was described as a *"challenge"* by student three. The success of the experiment was underpinned in one of the following responses, "*It was very great since we focus on one output idea and workout in each class with different subject to come up with different solutions (*Student 2). Student 3 stated, *"I am prepared to participate in another activity since I enjoy building the snail car,"* was remarked by Student 1. Additionally, Student 2 asserted that "*STEM is easier to learn than social studies."*

*Theme 4: Teamwork*

Improving teamwork skills PBL is currently a popular approach for learning in many Science, Technology, Engineering and Math (STEM)-related fields. Students learn to work in teams (Alves et al., 2012). Throughout the snail car construction, students mentioned working in teams. Student 1 commented that "*I learned to convert all knowledge with different subjects into a practical ordinated application via working in teamwork and building a prototype to achieve the required objectives".* They acknowledged teamwork as a factor in their perceptions of being engineers. Students regularly referred to working in teams during the snail car construction. They mentioned teamwork when they perceive themselves as engineers "*all of us wanted to complete the snail car"* (student 2). Student 3 mentioned the collaboration saying that *"we had a WhatsApp group to talk about our snail car".*

### 8.7.2. Teacher interview themes

The contents that emerged from the three proposed themes (effectiveness of STEM PBL in school, effectiveness of STEM PBL in student learning and external challenges) are given below.

*Theme 1: Effectiveness of STEM PBL in school*

Problem-based learning, as a pedagogical strategy within the STEM field, aims to encourage students to take an active role in their own learning by focusing on the solution of an open-ended, real-world challenge (Yew & Goh, 2016). PBL appears to be more effective than traditional teaching methodologies in terms of student retention of knowledge, or the assessment of student performance or skill (Khoshnevisasl et al., 2014; Zahid et al., 2016). Therefore, to demonstrate that STEM PBL is effective in this study, the success of PBL is discussed in the sub-themes below.

a) Success

Success is determined by a student's ability to complete a hands-on exercise and develop a prototype. Teachers who participated in this study acknowledged the effectiveness of the experiment and student engagement in this project-based learning activity. Teachers noted that students were disinterested in the theory portion of the experiment. Teacher 4 discovered that students "*do not want to collaborate online, but once the experiment was relocated to the school,* *they became fully engaged."*(Teacher 1). Thee of the teachers indicated that using STEM PBL contributed to the intervention's success. Students were enthusiastic about STEM PBL, as teacher 2 noted the "fun" in the way the snail car rubrics were followed to construct the vehicle. Teacher 4 confirmed that hands-on activities, including the construction of snail cars, are critical components of STEM teaching and are relevant to students' learning. Modelling a snail car in accordance with (Bandura, 1997) theory ensures its success. According to the theory, a student's ability to reproduce is enhanced by an attentive attitude, a capacity to access and retain information, motivation to learn, and a demonstration of the skills desired.

b) Autonomous thinking

Students' independence was acknowledged by teachers, who asserted that STEM PBL allows students to become more self-reliant. The PBL approach in STEM is in stark contrast to traditional classroom instruction, in which students are passive recipients of knowledge. In contrast, PBL requires students to generate solutions to problems using information and knowledge they may or may not possess. Teacher 2 observed that: "*students learned to convert all knowledge with different subjects into a practical ordinated application via working in groups,"* all four teachers claimed that by implementing STEM PBL, students gained increased independence in their learning, and teachers were able to transition from traditional teaching to facilitator roles.

c) Effectiveness of intervention

PBL, students investigate a real-world problem on their own with the help of a teacher who acts as a facilitator. Students became active role players after receiving the instructional guide, which included the objective for each curriculum, however the main purpose of the project was identified and described in the beginning of the activity. Students then began to independently undertake the task in groups, and formulate different solutions for the prototype, and consider the technical details derived from the knowledge they acquired during lessons. Teacher 2 noted that students' *knowledge and skills* had improved from when they began working with the prototype to the final stage of the project. It is evident that PBL is effective when the teacher becomes the facilitator. In the words of teacher 2, "*PBL in STEM provide a good balance across all STEM subjects* Teacher 4 adds that STEM BPL allows students to "*learn real-world projects*" (teacher 1) and that STEM PBL should form part of the school curriculum. STEM PBL is especially useful as an interdisciplinary methodology for teaching across disciplines. Another teacher is referring to PBL as a *"good balance across all STEM subjects"* (teacher 3).

d) Subject integration

Project-Based Learning (PBL) enhances students' learning experience in STEM subjects when integrated with real-life examples, such as building snail cars. Engaging students in practical applications of STEM fosters a deeper understanding of concepts and promotes critical thinking through the integration of PBL. Moreover, PBL contributes to the development of 21st century skills. It is through collaborative problem-solving, communication, and creativity that students are able to develop not only subject-specific knowledge, but also essential skills. Teacher 1 agreed that *PBL "is effective in STEM subjects "I firmly believe in the effectiveness of Project-Based Learning (PBL) within STEM subjects"*. This was also confirmed by Teacher 3, *"integrating PBL into our curriculum enhances students' understanding, allowing them to apply theoretical concepts to real-world problems".* PBL were specially praised by Teacher 2*, "cultivate a holistic understanding of STEM concepts. I found the snail car not only captivate students' interest but also encourage them to think creatively and collaboratively".*

e) Benefits of PBL teaching

PBL are engaging students in meaningful projects that reflect real-world challenges by focusing on hands-on, experiential learning rather than traditional teaching methods. This research has demonstrated that this pedagogical strategy promotes critical thinking, problem-solving skills, and collaborative abilities in addition to reinforcing subject knowledge. PBL's benefits in STEM subjects were also stressed by teachers*. "I've witnessed the positive impact when students build the snail car"*, Teacher 1. Therefore, PBL deepens students understanding but also sparks curiosity and enthusiasm for the subject matter. Teacher 2 says *"PBL encourages a growth mindset". I can see that the interdisciplinary nature of PBL in STEM subjects could mirror the complexity of real-world problems".* Furthermore, Teacher 1 observed *"it equips students with 21st Century skills". "PBL in STEM subjects nurtures a mindset of inquiry and a passion for lifelong learning"*, Teacher 3.

*Theme 2: Effectiveness of STEM PBL in student learning*

a) Critical thinking

Teachers agreed that STEM PBL enhances the development of critical thinking skills: "*In my class, I prefer to encourage critical thinking. As such, STEM PBLs are extending cognitive processes that were necessary for the snail car's completion"*(teacher 1). According to teacher 3, critical thinking in context of PBL: "*enables students to 'evaluate how the subject or project directly affects them"*. Teacher 2 agreed that: "*STEM PBL improves students critical thinking, which improves their learning* "and the snail car construction activity expanded the students' scope of critical thinking.

According to teacher 2: *"The intervention using STEM PBL with the experimental group increased and contributed the level of students understanding and the critical thinking skills since they always link their knowledge to enhance the designing of the project*". Most of all, teachers noted that students enjoyed the snail car activity, and in their opinion, the engagement alone serves as a primary reason for why STEM should be integrated into the school curriculum. The teachers also commented on the differences between the experimental and control group students. One of the responses was the following: "*The intervention using STEM PBL with the experimental group increased and contributed the level of students understanding and the critical thinking skills since they always link their knowledge to enhance the designing of the project however, the other group critical thinking is increased but with a limitation and students didn't link between different subjects. The handout sheets, presentations and interviews showed both groups critical thinking has improved but with the experimental groups it was highly increased. The intervention using STEM PBL with the experimental group increased and contributed the level of students understanding and the* *critical thinking skills since they always link their knowledge to enhance the designing of the project however, the other group critical thinking is increased but with a limitation and students didn't link between different subjects. The handout sheets, presentations and interviews showed both groups critical thinking has improved but with the experimental groups it was highly increased"* (teacher 3).

b) Problem-solving

Problem-solving is the ability to apply knowledge to find a solution. PBL focuses on real-life problems (Englander, 2002), and students are taught how to deal with them by using examples from real life. For this project, the students had to construct a prototype car using only materials and a few guidelines. Therefore, students had to apply their knowledge to construct a prototype. Throughout the interviews with teachers, it was evident that students had to apply their knowledge and one of the teachers commented that *this had improved their "problem solving skills"*(teacher 2). Furthermore, teacher 4 mentioned how *"knowledge and skills"* were prevalent during the snail car activity.

c) Collaboration

The snail car was a collaborative project that required students to design and construct the prototype as a team. STEM PBL emphasises collaboration as a key skill (Terada, 2021). In building the prototype, collaboration is evident. According to one of the teachers involved in the study, students found working in groups *"hard"* at the beginning, but later worked as a "unit" to complete the prototype (teacher 2). Teacher 4 observed that collaboration became easier as students became more *"familiar with each other".* Meeting students for the first time in person after several months of online learning is likely to be daunting for students and assigning them to work in groups may be challenging as well. However, the students were able to work in groups and complete the prototype because of their shared knowledge.

d) Creativity

Students' creativity can be enhanced through project-based learning (Issa & Khataibeh, 2021) when they are challenged with developing skills such as collaboration, planning, decision making, and time management. Using a PBL model, the author argues that students can think creatively more than when using conventional learning techniques. As a result, it has been confirmed that the PBL process is effective in advancing students' creative thinking processes (Mihardi et al., 2013). Through PBL, creativity is stimulated when students are motivated by a challenge and interested in the project. The four teachers reported student creativity in the form of material suggestions and how this could have led to a higher quality prototype of their snail car. It is also through this design process that hands-on experience improves creativity. It is usually during the design process that creativity occurs. Essentially, the findings coincide with study that shows PBL increases creativity and motivation in students (Ningsih et al., 2020). Usmeldi (2018) confirms that PBL increases creativity when used as a learning model.

*Theme 3: External challenges*

The teachers affirmed that the intervention took place during a time when students and teachers were not at school. One of teacher responses gathered talk about the snail car prototype and how it was difficult to explain a hand-on experiment online. Classes were conducted on Microsoft Teams, as COVID-19 regulatory measures had been in place by that point in time. Furthermore, one hundred and fifty students participated in the study, and not all eleventh-grade learners were able to attend school. Initially, the teachers came to the school on rotation, with only a few students, on Saturdays. "*The main challenge was gathering students in the school for doing projects, as school was on online during covid-19 pandemic where we success running the theoretical part online and the practical in (15) classrooms with capacity of ten students. Although there were only ten students in the classroom, students had to share materials to construct the snail car, and it became a constant task of cleaning and disinfecting the supplies. The other challenge was working in groups as this concept is new to my students it was hard in the beginning, but they used to it as they become familiar with each other"* (teacher 2). Additionally, the teachers needed to ensure that social distance rules were followed when assigning students to groups. Monitoring the students was always challenging. Also, students shared materials and were provided with plastic gloves. Some of the boys complained that wearing plastic gloves made their hands "sweaty" and "difficult" to work with.

### 8.7.3. Overlapping of student and teachers' themes

Upon the identification of these recurring trends, the objective is to combine an in-depth understanding of the viewpoints, and encounters articulated by students as well as teachers. The process entails the integration of insights from both datasets, enabling the construction of a comprehensive perspective that encompasses the intricacies and associations present in their respective replies.

As shown in Table 47, a remarkable intersection of themes emerges, uniting their perspectives on autonomous learning, critical thinking, subject integration, and collaboration. Based on these interviews, it is evident that both students and teachers appreciate autonomous learning, valuing its freedom and responsibility for acquiring knowledge. As well, their narratives emphasise a collective emphasis on the importance of cultivating critical thinking skills to navigate complexities and foster intellectual growth. Intertwined discussions about subject integration demonstrate a recognition of the value of connecting disciplines, enabling the creation of a holistic picture of knowledge that transcends disciplinary boundaries. Lastly, their voices resound when they emphasise the importance of collaborative environments, underscoring the importance of cooperation and the value of shared learning experiences.

Table 47. *Teacher and student theme overlapping*

| THEME | TEACHERS | STUDENTS |
|---|---|---|
| Autonomous learning | With the PBL pedagogy, teachers viewed themselves as facilitators. One teacher observed that students were able to "*convert their knowledge of various subjects into a practical application"* | Students took responsibility for their own prototype. One student noted that there was limited teacher intervention in the design process, stating *"limited output and working* in groups without the "teacher helping us to do it." |
| Critical thinking | One of the teachers found that *STEM PBL improves students critical thinking, which improves their learning"* and the snail car construction activity expanded the students' scope of critical thinking. | Students also mentioned that with STEM PBL *"I am capable of making connections outside of my classroom, and the experiment connected me to real-world problems."* |
| Subject integration | STEM is successful across the different subjects. STEM is successful across the different subjects. According to one teacher "*a real-life context that gave the students freedom to think for themselves; practical and interactive aspects; and a good balance across all STEM subjects?* | Another student commented on the effectiveness of STEM as an interdisciplinarity "*I learned to convert all knowledge with different subjects into a practical ordinated application"* |
| Collaboration | As can be seen in this response from a teacher, collaboration is effective "*collaboration became easier as students became more familiar with each other."* | STEM PBL facilitates effective collaboration "*working in teamwork and building a prototype to achieve the required objectives."* |

## 8.8. **General discussion and conclusion**

The qualitative themes were identified in this chapter. One addresses the efficacy of STEM PBL, while the other explores critical thinking skills. Notably, 21st century abilities were bolstered when STEM PBL is introduced. Simultaneously, the teachers observed the development of 21st-century skills as they progressed through the prototype's creation. This occurred notably during the intervention phase, when teachers noted an improvement in the critical thinking abilities of students in the experimental group. Additionally, the results indicated a significant increase in the student's level of motivation once their skills were strengthened. Based on the student and teacher interview responses it was clear that STEM PBL is particularly effective in teaching today's generation as described in Chapter 2. The PBL approach to learning involves students investigating, making decisions, designing, and concluding with a product based on task challenges. In STEM PBL learning, projects become the cornerstone of engineering design activities. Students enjoyed a hands-on activity where they could construct an object as a solution to a real-life problem. Students notably cited clean energy and environmental sustainability.

Students also developed critical thinking abilities, in addition to other 21st century skills required for university preparation, which is one of the UAE Ministry of Education's goals (MOE, 2016).

To answer the research question of this study, *How can a Project-Based Learning (PBL) promote effective learning?* Interviews were conducted with both students and teachers concerning Project-Based Learning (PBL) support the hypothesis. Based on these interviews, it was determined that PBL fosters an engaging and effective learning environment by incorporating real-life applications. Therefore, the interview findings provide support for this hypothesis. Through the integration of practical and hands-on activities, such as the construction of a snail car, students become actively involved in the learning process. Students can understand the relevance and applicability of what they learn when they apply theory to a real-life context. Construction and refinement of the snail car motivates students to work on it as they are motivated by the excitement and challenge of the task. The students become immersed in the process of problem-solving, critical thinking, and teamwork, which further enhances their engagement. Ultimately, the snail car project explore that engaging and meaningful learning environments can contribute to student engagement and learning effectiveness.

# SECTION V

## DISCUSSION AND CONCLUSION

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## CHAPTER 9.
## DISCUSSION AND CONCLUSION

A comprehensive summary of the research findings is presented in Chapter 9. We utilised adaptations of the STEM Semantics Survey and the Watson-Glaser Pearson Critical Thinking Test, and performed a practical experiment involving the development of a prototype snail car. We also conducted interviews to gather perspectives from both students and teachers. By combining quantitative and qualitative data, the research problem was addressed, the research questions answered, and the hypotheses tested. To conclude, we provide a comprehensive summary of the main findings and illustrate how they are consistent with the research objectives, and congruent with constructivism. The key insights and findings from Chapters 2, 3, 4, 5, 7 and 8 are frequently referred to throughout this chapter. Moreover, we acknowledge the limitations of the research before proposing recommendations and suggesting avenues for future research.

### 9.1. **Addressing the hypotheses (Study 1)**

Chapter 7 primarily aimed to gather quantitative data, to address hypotheses statements described in Chapter 4. The hypotheses statements were developed to show the relationship between project-based learning and critical thinking. Two hypotheses are presented as testable predictions:

1. The STEM interest of students who receive PBL intervention statistically differs from students who receive traditional instruction, with students receiving PBL intervention expected to be significantly more interested in STEM subjects.

2. We will find statistically significant differences in the critical thinking skills of students receiving PBL instruction in STEM and students receiving traditional instruction in STEM.

H1. *The STEM interest of students who receive project-based learning (PBL) intervention will differ statistically from students who receive traditional instruction, with students receiving PBL intervention expected to be significantly more interested in STEM subjects.*

Using the Relative Importance Index (RII) in the STEM Semantics Survey, it became evident that the experimental group, who were involved in PBL, demonstrated a significant preference for jobs in mathematics and science. The control group demonstrated the lowest RII in relation to science and its significance for their future professions. The experimental group showed a greater interest toward considering a career in science as compared to the control group. Moreover, the experimental group exhibited the importance of STEM disciplines and PBL for their prospective careers. The Relative Importance Index indicated that the experimental group had a significant level of competency in the skill of collaborative work.

Additionally, the experimental group exhibited a high level of proficiency in working collaboratively. Conversely, the control group faced difficulties in mathematics and displayed limited interest toward pursuing careers in science, thereby emphasising the crucial impact of PBL in nurturing interest in STEM. The hypothesis effectively supports that both traditional and PBL teaching approaches have a substantial influence on STEM interest and the development of 21st-century abilities. PBL has emerged as a significant catalyst, enhancing STEM interest and equipping students with essential skills for the 21st century. In contrast, the traditional teaching method appeared to reduce the inclination to pursue STEM careers among the control group. These findings align with Shaw's (2018) study on the interaction between PBL and STEM education, namely in promoting essential 21st-century abilities such as collaboration, communication, creativity, and critical thinking. The author emphasised that combining STEM with PBL is a strong method for cultivating these crucial abilities. In addition, Rehman et al. (2023) demonstrated that PBL had a substantial positive impact on students' capacity for collaboration and their level of active engagement. Amelia and Santoso (2021) provided additional evidence to support these findings, showing that PBL not only improves 21st-century skills in STEM subjects, but specifically strengthens abilities in communication, collaboration, critical thinking, and creative problem-solving.

H2. *We will find statistically significant differences in the critical thinking skills of students receiving project-based learning (PBL) instruction in STEM and students receiving traditional instruction in STEM.*

The responses obtained from the Watson and Glaser Critical Thinking Test provided significant insights into understanding the influence of project-based learning (PBL) on students' critical thinking skills. A clear distinction emerged between the experimental and control groups. The students who were exposed to PBL, which formed the experimental group, exhibited significant improvements in their critical thinking skills. Significantly, these students demonstrated substantial improvement in various aspects of critical thinking, including the ability to detect assumptions, recognise interferences, understand intricate information, make logical deductions, and critically analyse arguments.

Conversely, the control group, which did not have any PBL exposure, demonstrated only marginal enhancement in their critical thinking abilities. The clear distinction highlights the significant impact of PBL in improving critical thinking abilities. The statistical results are consistent with the research hypothesis, providing support for the idea that PBL instruction in STEM subjects improves students' critical thinking skills in comparison with traditional teaching methods. The pre-test and post-test scores show significant improvements in the critical thinking skills of the experimental group after the intervention, providing additional support for the hypothesis underlying assumption. Additionally, studies conducted by Eldiva & Azizah (2019), Insani et al. (2018), Issa & Khataibeh (2021), Terada (2021), and McDowell (2022) employing a Project-Based Learning (PBL) intervention collectively exhibited significant improvements in critical thinking abilities. Terada (2021) discovered that students showed a deeper understanding of complex topics, exhibited increased levels of analytical thinking (Issa & Khataibeh, 2021), and showed enhanced problem-solving skills (McDowell, 2022). These findings emphasise the achievements of PBL instruction in science, technology, engineering, and mathematics subjects, confirming its ability to improve students' critical thinking skills.

## 9.2. Answering the research question (Study 2)

The research question posed in Chapter 4, *"How can project-based learning (PBL) promote effective learning?"* fosters an exploration into multifaceted aspects that contribute to an enriched learning environment. PBL, when implemented effectively, promotes deeper engagement, collaboration, and critical thinking among students. First, it cultivates active participation by immersing students in real-world challenges, encouraging them to apply theoretical knowledge to practical situations. This approach sparks curiosity and intrinsic motivation, driving a more profound understanding of concepts. Second, PBL nurtures collaboration and communication skills as students work together to solve problems, fostering a sense of teamwork and shared responsibility. Third, it emphasises the development of critical thinking abilities by requiring students to analyse, synthesize, and evaluate information, enabling them to approach complex issues with creativity and resourcefulness. Moreover, PBL encourages autonomy and self-directed learning, empowering students to take ownership of their education and develop skills essential for lifelong learning. Thus, the research question delves into how PBL creates an effective learning ecosystem by encompassing engagement, collaboration, critical thinking, and autonomy as vital components of the educational process.

PBL also facilitates learning. Yuliani and Lengkanawati (2017) examined various instructional methods that promote independent learning, and one such method was project-based learning. According to their research, project-based learning enhances learner autonomy, including self-instruction, self-direction, self-access learning, and individualised instruction at every stage of PBL activities, including planning, implementation, and monitoring. As ChanLin (2008) also pointed out, PBL is an effective method of introducing students to self-directed learning. ChanLin

(2008) reports that students were more successful in learning if they engaged in web-based interactive activities that promoted self-direction, professional reasoning, and self-determination.

Stefanou et al. (2013) examined student self-regulation strategies in a project-based learning context to determine if there were differences in the outcomes of self-regulation among students. Collaboration, critical thinking, and metacognition were found to be more prevalent in project-based environments among students. In addition, Stefanou et al. (2013) found that students were more likely to perceive their instructors as being supportive of independent thinking and action in project-based courses.

The successes of PBL are underpinned in several studies. The findings of these studies indicate that critical thinking skills can be developed when PBL is incorporated into a STEM curriculum. PBL models incorporated into STEM have proven effective in improving critical thinking development (Rochim et al., 2021). Sarwi et al. (2021) and Noble et al. (2020) encourage inclusive STEM schools to adopt PBL approaches. PBL can effectively integrate STEM into the classroom (Navy & Kaya, 2020). Further, Rasul et al. (2016) found that PBL in STEM education enhances students' 21st-century skills by providing real-life experiences in solving authentic problems. Rochim et al. (2017) have shown consistently that integrating PBL models into STEM subjects improves learning outcomes in the areas of science, physics, and mathematics. Similarly, Markula and Aksela (2022) establish the effectiveness of project-based learning in science education. Noble et al. (2020) note that PBL can enhance students' interests and attitudes toward STEM subjects. Thus, it's evident from the cited literature that PBL has been shown to be a particularly effective method of integrating STEM into the classroom. This phenomenon was also observed in this research, particularly during the snail car experiment. In this process, teachers play a limited role, allowing students to take ownership of their learning.

PBL also fosters the development of critical thinking abilities in students, findings that are consistent with empirical evidence presented in this research, which indicates that students were able to solve problems and challenges in the real world more effectively. Students demonstrated an increased ability to critically evaluate potential solutions prior to arriving at a conclusion when building the snail car. Using real-life scenarios in PBL, Aranguiz et al. (2020) found that students are prompted to reflect on critical thinking and address sustainability issues confronting society today. Rochmahwati (2015) confirmed that PBL enhanced critical thinking capabilities in TEFL students, while Wibowo et al. (2018) discovered that PBL enhanced critical thinking abilities in science students. It has also been demonstrated that the use of PBL enhances overall critical thinking skills (Sasson et al., 2018). Moreover, Eldiva & Azizah (2019) found that PBL not only improved critical thinking skills, but also had a positive impact on students with special needs. Furthermore, Alawi and Soh (2019) substantiated the effectiveness of PBL in developing critical thinking in STEM education. Students who engaged in PBL-STEM learning demonstrated high levels of critical thinking (Eja et al., 2020).

As demonstrated by Trisdiono et al. (2019), multidisciplinary integrated project-based learning models make a significant contribution to the development of critical thinking skills and teamwork among elementary school students. During their study, Jusmaya and Efyanto (2018) found that project-based learning enhanced students' critical thinking skills. Mutakinati et al. (2018) claim that students developed critical thinking by incorporating project-based learning into STEM education.

A major outcome of STEM PBL is the development of critical thinking and communication skills, as identified by Oktavia & Ridlo (2020). In their study, the authors found that those with high levels of critical thinking skills demonstrated the ability to analyse arguments, those with moderate levels reached the simple explanation aspects, and those with low levels focused only on asking questions. It was concluded by the authors that the STEM method used in PBL motivated students to enhance their verbal communication skills and critical thinking abilities as they addressed challenges. The findings of this study are consistent with those of previous studies that have shown that project-based learning enhances critical thinking abilities through the development of creative problem-solving skills.

PBL also provides and effective learning environment for collaboration. As reported by Al Rasyid and Khoirunnisa (2021), PBL demonstrated robust collaboration skills, exceeding the predefined benchmarks for each collaboration skill indicator. Another study conducted by Papanikolaou and Boubouka (2010) examined the efficacy of collaborative scripts in promoting metacognitive knowledge in project-based e-learning. Throughout the study's design and evaluation phases, the authors observed that students followed a distinctive cooperation script, which allowed them to reflect both individually and socially. A study conducted by Weber (2019) examined the effectiveness of integrating collaboration technologies into project-based learning. The study involved the teaching of collaboration tools to students, who were able to articulate their collaborative processes during the sessions and displayed a decreased likelihood of engaging in conflicts or reporting on their peers. It has been concluded from the results that teaching student's collaboration skills and providing them with collaboration tools are essential (Weber, 2019).

In previous research (Alharbi et al., 2018), barriers to collaboration have been identified. This problem was addressed using a PBL approach, which yielded favourable results. In addition, PBL has been shown to be effective in enhancing online collaboration outcomes (García, 2016). In a virtual environment, the author found that PBL can significantly enhance learning. In their study, Trisdiono et al. (2019) suggested that PBL facilitates collaboration, while Markula and Aksela (2022) suggested that PBL explicitly encourages the use of collaboration for research, presentation of findings, and reflection on those findings. Additionally, de la Torre-Neches et al. (2020) highlighted the importance of PBL in promoting student participation and engagement. In addition, the impact of project-based learning on the collaboration skills of students with English as a Foreign Language (EFL) was examined (Andriyani & Anam, 2022). According to the cited literature, the present study found similar results to the positive effects of PBL collaboration when students were challenged with building a snail car.

In the research, it was found that students were able to accomplish specific, clearly defined goals within a social setting when they were motivated and enthusiastic. In addition, interviews with the students revealed that their collaborative abilities extended beyond being assigned to either the experimental or control groups. Through effective delegation of tasks, leveraging each other's ideas, and conquering tasks together, they developed collaboration skills. The peer contributions demonstrate the importance of learning and collaboration in the success of the snail car experiment. Moreover, the students established a WhatsApp group to facilitate better communication and collaboration.

In line with the findings of the research studies consulted and the qualitative data gathered from student and teacher interviews, PBL is shown to enhance critical thinking, improve collaboration, and promote autonomous learning. This research consistently found that PBL positively influences critical thinking skills. Through PBL, students are challenged to think critically, to analyse complex problems, and to solve them. Through active engagement with real-world challenges, students gain a more comprehensive understanding of the subject matter. Moreover, qualitative data collected from both students and teachers support the notion that PBL promotes collaboration. PBL projects require students to work in teams, exchange ideas, share resources, and negotiate tasks. The creation of collaborative environments facilitates communication, collaboration, and the development of social and emotional skills.

In addition, PBL aligns with Piaget's theory of cognitive development and constructivism's emphasis on knowledge construction through experience. Thus, PBL facilitates student engagement in the learning process. It has been found that PBL provides students with engaging and relevant learning experiences by focusing on scientific principles and concepts, involving them in meaningful problem-solving activities, and allowing them autonomy to construct knowledge and create products independently, according to the research findings. PBL, however, requires a careful design, and critical thinking plays a crucial role in encouraging student engagement. It is important for a PBL setting to be authentic, to allow students to voice their opinions, to offer them a choice, and to solve complex problems. Furthermore, this approach stimulates student motivation and interest, through the use of realistic learning activities. In this research, PBL was found to provide an environment for students to engage in effective learning. As students work collaboratively towards a common goal, this strategy enables them to learn both content and 21st-century skills.

## 9.3. **Research contribution**

Research on STEM project-based learning is an effective method for evaluating its impact on students' ability to develop critical thinking skills. Learning more about STEM PBL provides educators and parents with a better understanding of its effectiveness and credibility, as well as consideration of important factors for ensuring the appropriate development of skills and qualities in students. Furthermore, this research addresses gaps in previous research regarding the cultivation of critical thinking through project-based learning in the United Arab Emirates. This research differs from previous research in terms of its unique approach to research methods. In this research, students were asked to construct prototypes that would be applied in real-life situations, providing an authentic representation of project-based learning. In addition to exploring the nuances of PBL, this research presents an accurate analysis of how it can be implemented in the classroom. Additionally, the research's findings and the framework of key characteristics developed as a result may be of use to both teachers and researchers. Moreover, the insights from this research can assist in the training of new teachers to enable them to effectively incorporate project-based learning into their teaching.

## 9.4. Limitations

Throughout the research process, COVID-19 presented significant challenges, which impacted the snail car construction. Several essential measures were implemented to ensure student participation. Among the requirements were obtaining approval from senior management and parents, adhering to strict COVID-19 protocols, and arranging for health professionals to conduct weekly polymerase chain reaction (PCR) COVID tests on both students and teachers.

Due to limitations and students' unavailability for Zoom interviews, it was not possible to interview the number of students originally selected. Therefore, only a few students were able to participate in the interview process. Although this research demonstrated the positive impact on critical thinking skills that STEM PBL can have, a larger sample size and in-person interviews would have provided more insight into the process.

The sampling method used in this research study makes incidental allocation impossible. The lack of incidental allocation could cause biases due to the elimination of randomisation, The reason for this was that all 11$^{th}$-grade boys from the vocational high school were included in this research study. Therefore, no specific criteria were established for the 11th-grade boys, since they were chosen according to the research objectives.

There are also limitations to this research with respect to the assignment of the control and experimental groups. As all 11th-grade boys were enrolled in science, technology, engineering, and mathematics courses, there were no predetermined criteria for assignment. We divided the boys into control and experimental groups without regard to their academic performance in these STEM subjects. This results in a limitation because there are no specific criteria for the two groups. This study's purposive sampling approach may be responsible for this limitation. The research also had the limitation that no pre-test of the STEM Semantics Survey was conducted.

## 9.5. Suggestions for future research

To understand the factors influencing student engagement and learning outcomes, future research should examine both the dynamics of the experimental group and the control group during project-based learning (PBL). For this purpose, it would be beneficial to investigate the characteristics of students, including their prior knowledge, learning styles, and motivation levels, and how these factors interact with PBL activities. In addition, it would be important to explore how teamwork, collaboration, and communication can be nurtured during PBL to facilitate effective teamwork, collaboration, and communication among students. It is important to examine the interpersonal relationships among students, as well as potential power imbalances that may hinder group dynamics and impede effective communication within groups. Moreover, research should examine the role of teachers as facilitators in resolving conflicts that may arise within PBL groups. The consideration of these aspects will facilitate a more comprehensive understanding of the dynamics and effectiveness of PBL. Furthermore, it is imperative to conduct further research on the effectiveness of project-based learning as an instructional method beyond the positive outcomes reported in this study. When PBL does not produce the desired results, it can provide insight into the challenges and limitations associated with this strategy, informing instructional practices and strategies for optimizing the implementation of PBL in diverse educational settings.

It is suggested that an extensive investigation be conducted aimed at elucidating the complex intricacies of project-based learning (PBL) within the context of STEM disciplines, emphasising its impact on student engagement, contentment, and motivation. In exploring this element in greater depth, we may gain greater insight into the complex ways in which PBL can enhance the educational experiences of students in these critical fields. A thorough examination of the interaction between PBL and science, technology, engineering, and mathematics disciplines can reveal valuable knowledge that could improve pedagogical approaches and improve student performance. This could lead to a more dynamic and thriving educational environment.

Furthermore, artificial intelligence (AI) in project-based learning is a promising avenue for future research that will be relevant during the Fourth Industrial Revolution and enhance the educational experience for high school students in STEM subjects. Using AI, students can gain access to valuable tools and resources that assist them in their project work and facilitate deeper learning. With the help of AI algorithms, students can collect and analyse data, draw meaningful conclusions, and make well-informed decisions. The use of AI-powered virtual simulations and modelling platforms can also provide students with a dynamic and interactive environment in which to experiment and explore complex scientific concepts. The use of artificial intelligence can further enhance the learning experience by adapting content and challenges to the individual needs of students and providing them with timely feedback on their progress. Using AI to enhance project-based learning can cultivate critical thinking skills, problem-solving skills, and collaboration skills, preparing students for the challenges of the future. Future research in this field could explore the specific implementation strategies, evaluate the efficacy of AI-integrated project-based learning models, and examine the long-term effects on student engagement, achievement, and career readiness.

Moreover, this research recommends that vocational education, particularly in STEM fields, be prioritised as a crucial strategy for addressing the gender gap in engineering and other STEM opportunities. Particularly for female students in the UAE, Alzaalbi et al (2021) discovered that females in this field are deserting their profession due to a lack of opportunities, a lack of role models, and gender disparities. Further research is needed to determine how mentorship programs and targeted support can mitigate biases that have hindered women's participation in STEM fields.

## 9.6. **Conclusion**

This research examined the impact of a project-based learning on critical thinking n a group of 11th-grade students in a high school in the United Arab Emirates. According to this study, PBL should be integrated into STEM subjects (Asghar et al., 2012; Han et al., 2016) to make them student-led, as well as be integrated among STEM disciplines so that students can form associations and retain information.

### The research goals included several objectives.

Using project-based learning (PBL) as the first objective, we determined that PBL positively affects students' interest in STEM subjects. To determine whether PBL affects students' STEM engagement, we compared interest levels among the control and experimental groups. The STEM Semantics Survey analysis revealed notable differences between the experimental group receiving PBL instruction and the control group receiving traditional instruction. The experimental group showed markedly higher interest in STEM subjects and exhibited more inclination toward STEM careers. In this research, we demonstrated that PBL can enhance STEM subjects' interest among students interested to pursue careers in these fields. The STEM Semantics Survey demonstrated that PBL instruction increased interest in STEM subjects among grade 11 students, especially the experimental group.

The integration of PBL played a crucial role in attaining the specified goals aimed at enhancing 21st-century competencies, particularly in critical thinking, collaboration, communication, and teamwork. By engaging in PBL activities, students were fully involved in a complex project, such as constructing a prototype of a snail vehicle, which required them to employ critical thinking and problem-solving skills. They successfully handled challenges that necessitated the critical assessment of knowledge, the development of inventive solutions, and outcomes, thus enhancing their critical thinking skills. Furthermore, the collaborative nature of the snail car prototype fostered a conducive environment for collaboration and communication. Students acquired the skills to proficiently articulate thoughts, attentively engage in listening, and cooperate with their peers.

In the second objective, we examined the impact of PBL instruction in STEM on the development of critical thinking skills by considering changes in critical thinking skills before and after PBL interventions.

It was found that students who participated in PBL instruction demonstrated significant improvement in critical thinking skills than students who received traditional instruction. Consequently, PBL played an important role in fostering and enhancing students' critical thinking skills within STEM fields in our sample.

The third objective recognised that PBL can create effective learning for students in STEM disciplines from the perspective of teachers and students. PBL's contribution to enhancing the learning environment in STEM education was highlighted in this research, which successfully met its third objective. The interviews done to investigate how PBL enhances effective learning yielded important insights. These interview findings confirm the idea that PBL provides an engaging learning environment. The implementation of PBL significantly enhanced the development of 21st-century skills, as observed by both teachers and students during the building of the snail car prototype. During the intervention phase, teachers noticed a clear improvement in the critical thinking skills of pupils in the experimental group. The student acquired and honed essential skills in critical thinking, problem-solving, communication, and collaboration. It is evident from the evidence that PBL has a positive impact on the learning environment, which supports its value as a pedagogical approach in STEM education.

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# APPENDIX 1:
## Guardian Permission form

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### GUARDIAN PERMISSION FORM FOR RESEARCH

**Title of Project: Using a STEM Project-Based Learning approach to foster the Development of Critical Thinking Skills in Vocational High Schools in the United Arab Emirates.**

عنوان البحث :أستخدام مدخل التعلم القائم على المشروعات (STEM Project-Based Learning)
لتعزيزوتنميةمهاراتالتفكيرالنقديفيالمدارسالثانويةالمهنيةبدولةالإماراتالعربيةالمتحدة.

**Researcher: Ibrahim Khalaf Saleh Alzaabi**

الباحث : إبراهيم خلف صالح الزعابي

It is kindly requested that you grant your son permission to participate in this study. Please read the following information carefully before making you decision.

نسعى للحصولعلىالإذنمنكبمشاركة ابنكم فيهذهالدراسة. يرجىقراءةالمعلوماتالتاليةبعنايةقبلأنتقررماإذاكنتستمنحالإذنأملا.

**Purpose of the research:** The purpose of this study is to investigate the effectiveness of the STEM Project-Based Learning approach towards enhancing critical thinking skills amongst Emirati high school students.

الغرضمنهذهالدراسة: ان الغرض من هذه الدراسة هوالتحققمنفعاليةنهجالتعلمالقائمعليمشروعالعلوموالتكنولوجياوالهندسةوالرياضياتفيتعزيزمهاراتالتفكيرالنقدييبنطلابالمدارسالثانويةفي دولة الامارات العربية المتحدة.

**Procedure to be followed**: During testing, your son will progress through a STEM PBL course and will participate in group-based learning wherein he will be instructed to build prototypes of technological forms, to grade his critical thinking skills.

الخطوات المتبعة :اثناءالاختبار،سيخضعابنكلدورة STEM PBL وسيشاركفيالتعلمالجماعيحيثيتعينعليهبناءنماذجأولية وسيتماختبارمهاراتالتفكيرالنقديليه.

**Discomforts/risks**: The risks in this study are minimal. There are no foreseeable discomforts or dangers to either you or your son in this study.

المضايقات / المخاطر: مقدارالمخاطرفيهذهالدراسةضئيل.
لاتوجدمضايقاتأومخاطرمتوقعةلكأولابنكفيهذهالدراسة.

**Incentives/benefits for participation**: Participating in this research will be very beneficent to your son. The results will also increase our knowledge with regards to the effect that STEM PBL has on students' thinking skills.

مزايا المشاركة:ستكونالمشاركةفيهذاالبحثمفيدةجداًلابنك. وستزيدالنتائجأيضًامنمعرفتنابتأثير طريقة التعلم بواسطة المشاريع (STEM Project-Based Learning) عليمهاراتالتفكيرلديالطلاب.

**Duration of participation**: Participation in the study will not exceed 16 weeks.

مدة المشاركة: مدة المشاركة في هذه الدراسة لن تزيد عن ستة عشر أسبوع.

**Statement of confidentiality**: All records will be kept confidential and will only be available to professional researchers and staff. If the results of this study are published, the data will be presented in a group format, and individual students will not be identified.

السرية :يتمالاحتفاظبجميعالسجلاتبسريةولنتكونمتاحةإلاللباحثينالمحترفينوالموظفين. إذاتمنشرنتائجهذهالدراسة،فسيتمتقديمالبياناتعليشكلمجموعةولنيتمتحديدطالببمفردة.

**Voluntary participation**: Your son's participation is voluntary. If you feel your son has in any way been coerced into participation, please inform the faculty advisor. We also ask that you read this letter to your son (if age-appropriate) and inform him that participation is voluntary. At the time of the study, your son will once again be reminded of this by the researcher.

المشاركة الطوعية: مشاركةابنكتطوعية. إذاشعرتأنابنكقدأُجبربأيشكلمنالأشكالعليالمشاركة،فيرجيإبلاغمستشار الكلية. كمانطلبمنكقراءةهذهالرسالةلابنك (إذاكانمناسبًالسنه) وإبلاغهأنالمشاركةطوعية. فيوقتالدراسة،سوفيقومالباحثبتذكيرابنكبذلكمرةأخرى.

**Termination of participation**: If at any point during the study, you or your son wishes to terminate the session, we will do so.

إنهاء المشاركة :إذارغبتأنتأوابنكفيإنهاءالجلسةفيأيوقتأثناءالدراسة،فسنقومبذلك.

Questions regarding the research should be directed to:

Mr. Ibrahim Khalaf Alzaabi (x-XXXX)

يجبتوجيهالأسئلةالمتعلقةبالبحثإلى:

السيد إبراهيم خلف صالح الزعابي (x-XXXX)

Questions or concerns regarding participation in this research should be directed to:

Mr. Ibrahim Khalaf Alzaabi (x-XXXX) or

يجب توجيه الأسئلة أو المخاوف المتعلقة بالمشاركة في هذا البحث إلى:

السيدإبراهيمخلفصالحالزعابي (x-XXXX)

This research has been reviewed and approved by the Institute of Applied Technology Review Board. If at any time before, during, or after the experiment; your son experiences any physical or emotional discomfort that is a result of his participation, or if you have any questions about the study or its outcomes - please feel free to contact us.

Parent Signature Box________________________________________________

I, the parent or guardian of a minor, years of______________________________

Age____________________________________________________________

permit his/her participation in the program of research outlined above that is being conducted by Mr Ibrahim Khalaf AlZaabi.

Signature of Parent or Guardian___Date________________________________

Please print your name here.___________________________________________

Student Signature Box_______________________________________________

I,___________________________, agree to participate in the program of research outlined

above, and understand that my participation is voluntary.

Signature of Student___Date___________________________________________

Please print your name here.____________________________________________

Signature of researcher:__________________________________________

Date:________________________________________________________

**Please note**: For research involving minors, student assent should be sought whenever possible. At times, this may entail creating a separate consent document for parents and students (each written in age-appropriate language), of which both must be signed. At other times, parents may be required to make the decisions on behalf of for their children. Please be aware that participants give consent, parents give permission, and minors give assent. Documents should contain the appropriate terms.

يرجى الملاحظة: بالنسبةللأبحاثالتيتشملالقصر،يجبالسعيللحصولعليموافقةالطالبكلماأمكنذلك. فيبعضالأحيان،قد يستلزمذلكإنشاءوثيقةموافقةمنفصلةللآباءوالابن (كلمنهامكتوببلغةمناسبةللعمر) ويجبتوقيعكلمنهما. فيأوقاتأخر ى،قديُطلبمنالوالديناتخاذالقرارللابن. يرجيالعلمأنالمشاركينيمنحونالموافقة،ويمنحالوالدانالإذن،ويعطيالقاصرونال موافقة. يجبأنتحتويمستنداتكعليالمصطلح

# APPENDIX 2:
## Student Informed Consent Form

### STUDENT INFORMED CONSENT FORM

VOLUNTARY CONSENT FORM:

I have read and understood the information on this form, and I consent to the terms of this research. I understand that my responses are completely confidential, I have the right to withdraw at any time, and I have received an unsigned copy of this Informed Consent Form to keep in my possession.

Student ID:______________________________________________________________

Student Name: ____________________________________________________________

Section: ________________________________________________________________

Signature: ______________________________________________________________

Date: ___________________________________________________________________

I certify that I have explained to the above individual the nature of, the purpose of, and the potential benefits of this study; associated with participants in this research, and have answered any questions that I have been given.

| ______________________________ | ______________________________ |
| --- | --- |
| Date | Principal Investigator's |

# APPENDIX 3:

## Principal study consent approval letter

ثانوية التكنولوجيا التطبيقية
Applied Technology High School

August 30, 2020

| | |
|---|---|
| From : | Kareem Ragab |
| | Principal- Applied Technology High School – Umm Al Quwain |
| To: | Ibrahim Khalaf Saleh Khalaf Alzaabi. |
| | PhD student University of Cordoba Spain. |

**ATHS Ethical Clearance / Project Approval.**

As per the approval of Dr.Ahmed Alawar Managing Director of the Institute of Applied Technology on August 7th,2019, the research titled " Using STEM Project based approach in developing critical thinking in vocational high schools in UAE" has been reviewed and approved by UAQ campus panel.

It was evaluated twice ( as minimal project adjustments were made ) based on ethics standards and ATHS polices and guidelines. The UAQ ATHS hereby finds that:

(a) the project and procedures pose no risk beyond minimal and that it complies with research ethics requirements;
(b) the project has merit and relevance to the ATHS and to the UAE Vision 2021 and the Science , Technology, and Innovation policy of the UAE.

Therefore, the research project has received full ethical clearance for the design and procedures described.

We wish you the best of luck with this research project.

Kareem Ragab
UAQ- Principal
+971 56 188 2119

# APPENDIX 4:

## STEM PBL Teacher Training Program

| | |
|---|---|
| Day one | Call for STEM experts at all the campuses who will facilitate PBL training as PDs during July 5-9. (Zoom videoconferencing)<br>Criteria:<br>Knowledge of real-world topics and STEM careers<br>Should have practical experience of student-centred learning<br>Experience with hands-on activities in the classroom<br>Know how to engage students<br>Use icebreakers<br>Teachers need to send examples either in a video or PPT to showcase their knowledge of PBL |
| Day two | Call for STEM experts at all the campuses who will facilitate PBL training as PDs during week July 5-9. (Zoom videoconferencing)<br>Criteria:<br>Knowledge of real-world topics and STEM careers<br>Should have practical experience of student-centred learning<br>Experience with hands-on activities in the classroom<br>Know how to engage students<br>Use icebreakers<br>Teachers need to send examples either in a video or PPT to showcase their knowledge of PBL |
| Day 3 & 4 | Notify selected STEM experts (teachers)<br>The training should include examples to engage students, use a PPT of video to demonstrate a "project" (hands-on activity) |
| Day 5 | PD outline Day 1<br>**1.** Learn the basics of STEM PBL<br>**2.** How to build authentic STEM lessons in the class to develop critical thinking |
| Day 6 | PD outline Day 2<br>**1.** STEM experts share their STEM videos<br>**2.** STEM experts share experiences how to engage students |
| Day 7 | PD outline Day 3<br>Q&A session<br>STEM PBL test (only Dubai Campus)<br>Maybe certificates for completing the training |
| Day 8 | Selection of 3 teachers |

# APPENDIX 5:

## Suggestions for designing the STEM training programme

### SUGGESTIONS FOR DESIGNING THE TRAINING PROGRAMME IN STEM (STUDENTS)

| ELEMENTS | | EXPERIMENTAL GROUP | NON- EXPERIMENTAL GROUP |
|---|---|---|---|
| Competences | | | |
| Subjects | | | |
| Objectives | | | |
| Contents | Concepts | | |
| | Skills | | |
| | Attitudes | | |
| Methodology | Teaching model | | |
| | Psycho-pedagogical principles | | |
| | (...) | | |
| Temporisation | | | |
| Sessions | Activities | | |
| Resources | Materials | | |
| | Team | | |
| | (...) | | |
| Classroom organization (student distribution) | | | |
| Assessment | Assessment stan-dards | | |
| | Tools | | |
| | Temporisation | | |
| (...) | | | |

Training programmes must have a sufficient number of sessions to ensure the acquisition of content and the development of competences.

You must justify the number of sessions.

The STEM-based training plan for the students should be detailed and show a comparison with the training plan to be followed by the students in the control group. This will also allow you to set the variables you want to measure.

If there are 3 teachers who will implement the program, this will also be a variable to consider in the research results.

# APPENDIX 6:

## Teacher's guide for STEM Project-Based Learning approach

### TEACHER'S GUIDE

Course name: STEM PBL Grade 11

Course Code: SEM009

### TABLE OF CONTENT

# APPENDIX 7:

## Original STEM Semantics Survey

### STEM Semantics Survey

Gender: M / F

This five-part questionnaire is designed to assess your perceptions of scientific disciplines. It should require about 5 minutes of your time. Usually it is best to respond with your first impression, without giving a question much thought. Your answers will remain confidential.

| | |
|---|---|
| ID: ______________<br>School: ______________ | Use the assigned ID or the year and day of your birthday (ex: 9925 if born on the 25th day of any month in 1999. |

**Instructions: Choose one circle between each adjective pair to indicate how you feel about the object.**

To me, SCIENCE is:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | fascinating | (1) | (2) | (3) | (4) | (5) | (6) | (7) | ordinary |
| 2. | appealing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unappealing |
| 3. | exciting | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unexciting |
| 4. | means nothing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | means a lot |
| 5. | boring | (1) | (2) | (3) | (4) | (5) | (6) | (7) | interesting |

To me, MATH is:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | boring | (1) | (2) | (3) | (4) | (5) | (6) | (7) | interesting |
| 2. | appealing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unappealing |
| 3. | fascinating | (1) | (2) | (3) | (4) | (5) | (6) | (7) | ordinary |
| 4. | exciting | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unexciting |
| 5. | means nothing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | means a lot |

To me, ENGINEERING is:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | appealing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unappealing |
| 2. | fascinating | (1) | (2) | (3) | (4) | (5) | (6) | (7) | ordinary |
| 3. | means nothing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | means a lot |
| 4. | exciting | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unexciting |
| 5. | boring | (1) | (2) | (3) | (4) | (5) | (6) | (7) | interesting |

To me, TECHNOLOGY is:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | appealing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unappealing |
| 2. | means nothing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | means a lot |
| 3. | boring | (1) | (2) | (3) | (4) | (5) | (6) | (7) | interesting |
| 4. | exciting | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unexciting |
| 5. | fascinating | (1) | (2) | (3) | (4) | (5) | (6) | (7) | ordinary |

To me, a CAREER in science, technology, engineering, or mathematics (is):

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | means nothing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | means a lot |
| 2. | boring | (1) | (2) | (3) | (4) | (5) | (6) | (7) | interesting |
| 3. | exciting | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unexciting |
| 4. | fascinating | (1) | (2) | (3) | (4) | (5) | (6) | (7) | ordinary |
| 5. | appealing | (1) | (2) | (3) | (4) | (5) | (6) | (7) | unappealing |

# APPENDIX 8:

## STEM Semantics Survey Adaptation

### IMPLEMENTING STEM IN EDUCATION TO ENHANCE CRITICAL THINKING SURVEY – STUDENTS [1]

As you read each sentence, you will know whether you agree or disagree. Select the box that describes how much you agree or disagree.

This is not timed; work fast, but carefully. There are no “right” or “wrong” answers!

### MATHEMATICS

| MATHEMATICS | STRONGLY DISAGREE | DISAGREE | NEITHER AGREE NOR DISAGREE | AGREE | STRONGLY AGREE |
|---|---|---|---|---|---|
| 1. Math has been my worst subject. | ❏ | ❏ | ❏ | ❏ | ❏ |
| 2. I would consider a career that uses math. | ❏ | ❏ | ❏ | ❏ | ❏ |
| 3. Math is difficult for me. | ❏ | ❏ | ❏ | ❏ | ❏ |
| 4. I am the sort of student who excels at math. | ❏ | ❏ | ❏ | ❏ | ❏ |
| 5. I can handle most subjects, but I can't do well at math. | ❏ | ❏ | ❏ | ❏ | ❏ |
| 6. I am capable of advanced work in math. | ❏ | ❏ | ❏ | ❏ | ❏ |
| 7. I can get good grades in math. | ❏ | ❏ | ❏ | ❏ | ❏ |
| 8. I am good at math. | ❏ | ❏ | ❏ | ❏ | ❏ |

## SCIENCE

| SCIENCE | STRONGLY DISAGREE | DISAGREE | NEITHER AGREE NOR DISAGREE | AGREE | STRONGLY AGREE |
|---|---|---|---|---|---|
| 1. I am confident in my ability in science. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 2. I would consider a career in science. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 3. I expect to find science useful outside of school. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 4. Knowing science will help me earn a living one day. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 5. I will require science as a subject for my future work. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 6. I know I can do well in science. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 7. Science will be an important part of my life's work. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 8. I can handle most subjects, but I can't do well in science. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 9. I am capable of advanced work in science. | ❑ | ❑ | ❑ | ❑ | ❑ |

## ENGINEERING AND TECHNOLOGY

Please read this paragraph before you answer the questions.

يرجيقراءةهذهالفقرةقبلالإجابةعلياألسئلة

Engineers solve problems through research and creativity, and with their knowledge in science. There are different types of engineers: biomedical, environmental, civil, mechanical, computer, electrical, and chemical. Technologists design things such as amusement parks, virtual reality programs, food, fabric, cars, and bridges. They improve things and create things that people can use in their day-to-day lives.

| ENGINEERING AND TECHNOLOGY | STRONGLY DISAGREE | DISAGREE | NEITHER AGREE NOR DISAGREE | AGREE | STRONGLY AGREE |
|---|---|---|---|---|---|
| 1. I like to imagine new products. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 2. If I study engineering, I can improve things that people use every day. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 3. I am good at building and fixing things. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 4. I am interested in what makes machines work. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 5. Designing new products will be prudent to my future endeavors. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 6. I am curious about how electronics work. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 7. Creativity and innovation is important to my future work. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 8. Knowing how to use math and science together will allow me to invent useful products. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 9. I believe that I can have a successful career in engineering. | ❑ | ❑ | ❑ | ❑ | ❑ |

## 21ST CENTURY SKILLS

| 21st CENTURY SKILLS | STRONGLY DISAGREE | DISAGREE | NEITHER AGREE NOR DISAGREE | AGREE | STRONGLY AGREE |
|---|---|---|---|---|---|
| 1. I am confident I can lead others in accomplishing a set goal. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 2. I am confident I can encourage others to do their best. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 3. I am confident I can produce high quality work. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 4. I am confident I can respect the differences of my peers. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 5. I am confident I can be of assistance to my peers. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 6. I am confident I can include others' perspectives when making decisions. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 7. I am confident I can adapt to situations, and make changes, when things do not go as planned. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 8. I am confident I can set my own learning goals. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 9. I am confident I can manage my time wisely when I need to complete work. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 10. When I have multiple assignments, I can prioritize which need to be completed first. | ❑ | ❑ | ❑ | ❑ | ❑ |
| 11. I am confident I can work alongside students from diverse backgrounds. | ❑ | ❑ | ❑ | ❑ | ❑ |

# APPENDIX 9:

## Expert letter – STEM Semantics Survey

ثانوية التكنولوجيا التطبيقية
Applied Technology High School

December 22, 2023

From: Kareem Ragab
Principal-Applied Technology High School Dubai

To: Ibrahim Khalaf Saleh Alzaabi
PhD Student University Of Cordoba - Spain

Subject: **Technical support letter STEM Semantics Survey**

First of all, I would like to thank you for consulting me regarding your PhD project, titled " Using STEM Project-Based Learning approach to foster STEM interest and the development of critical thinking in a vocational high school in the UAE". I am providing my feedback in this letter as an assessment specialist and School principal. The questions developed in the semantics survey are of high quality aiming to measure student's interest in mathematics, science, Engineering Technology and 20st century skills. In general, all questions are mapped accurately with the interests intended to be measured.

Kareem Ragab
Dubai Principal
+971561882119

# APPENDIX 10:

## Expert letter 2 STEM Semantics Survey

ثانوية التكنولوجيا التطبيقية
Applied Technology High School

December 19, 2023

From: Mohammed Abdou
Acting Vice Principal-Applied Technology High School Dubai

To: Ibrahim Khalaf Saleh Alzaabi
PhD Student University Of Cordoba - Spain

Subject: **Technical support letter STEM Semantics Survey**

First of all, I would like to thank you for developing the survey mentioned above and for consulting me regarding your PhD project, titled " Using STEM Project-Based Learning approach to foster STEM interest and the development of critical thinking in a vocational high school in the UAE". I am providing my feedback in this letter as an assessment specialist and School principal. The questions developed in the semantics survey are of high quality aiming to measure student's interest in mathematics, science, Engineering Technology and 20st century skills. In general, all questions are mapped accurately with the interests intended to be measured.

Mohammed Abdou
Dubai Acting Vice-Principal
+971506490234

# APPENDIX 11:

## Original Watson and Glaser critical thinking test copy

### WATSON–GLASER

Original Watson and Glaser Critical Thinking Test.pdf

# APPENDIX 12:

## Expert letter 1 Watson and Glaser Critical Thinking

كليات التقنية العليا
HIGHER COLLEGES OF TECHNOLOGY

Subject: Technical support letter for critical thinking pre-test and post-test.

Dear Mr. Ibrahim,

First of all I would like to thank you for consulting me regarding your PhD project, titled "STEM education for improving critical thinking skills". I am providing my feedback in this letter as an assessment specialist and engineering faculty.

The questions developed in the tests are of high quality aiming to measure high cognitive levels, such as application, analysis and evaluation which are the main elements of critical thinking skills, the practical tasks developed focus on creating level based on proper design aspects.

In general, all questions are mapped accurately with the skills intended to be measured. Wish you can share with me the results of your study once project is done.

Sincerely

Kamal Abuqaaud

Lecturer - Engineering Technology and Science

Faculty of Engineering

27 August 2020

Direct.: +9712 206 6620
Email: kabuqaaud@hct.ac.ae
P.O.Box: 7947, Sharjah, United Arab Emirates

# APPENDIX 13:

## Expert letter 2 Watson and Glaser Critical Thinking

ELECTRICAL AND ELECTRONICS ENGINEERING SCIENCE
FACULTY OF ENGINEERING

Dr Moin Hanif

Work Tel: +27 (0)115592213
Mobile: +27(0) 842233063
Email1: moinh@uj.ac.za
Email2: moinhanif@ieee.org

27 August 2020

Dear Mr. Ibrahim,

**Technical support letter for critical thinking pre-test and post-test**

I have gone through both the pre-test and post-test you have sent to me that assesses a students' critical thinking skills. These tests definitely asses one's ability to think clearly and rationally. I do believe your work is going to be a valuable contribution to STEM education and help explore more about the logical connection between ideas.

Yours truly,

...............................................

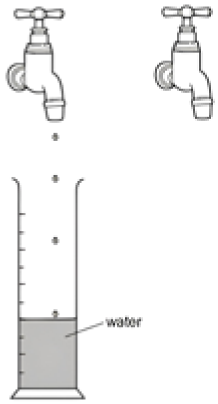
Moin Hanif

OFFICIAL ADDRESS I Cnr Kingsway and University Road Auckland Park
PO Box 524 Auckland Park 2006 I Tel +27 11 559 4555 I www.uj.ac.za
Auckland Park Bunting Campus I Auckland Park Kingsway Campus
Doornfontein Campus I Soweto Campus

UNIVERSITY OF JOHANNESBURG

# APPENDIX 14:

## Sample of the adaptation of the Watson and Glaser critical thinking test

| ORIGINAL QUESTION | NEW QUESTION |
|---|---|
| **Task 8**: Inference<br><br>Waterfall fills a lake in 6 days while aqueduct fill the same leak in 4 days, how many hours both will take to fill the lake if they start together.<br><br> | **Task 8**: Inference<br><br>Tap A fills the tube in 10 minutes, while tap B fills the tube in 20 minutes, if both taps start filling the same tube together, how long does it take to fill the tube?<br><br> |
| **Task 4**: Recognition of assumptions<br><br>A cat is chasing a rabbit with a distance between them 1 meter, if the speed of the cat is 5 m/s and the speed of the rabbit is 16 m/s how long it will take the cat to hunt the rabbit?<br><br> | **Task 4**: Recognition of assumptions<br><br>The initial distance between two cars is 40 Km, if the speed of the red car is 60 km/h and the speed of the blue car is 40 km/h, how long it takes the red car to pass by the blue car?<br><br> |

# APPENDIX 15:

## Marks matrix

Assessment strategy for MSE subjects during term one

| Test 1 | Test 2 | Online quizzes | Learning by doing projects interdisciplinary approach "Five projects" + Main project | A comprehensive final exam |
|---|---|---|---|---|
| 15% | 25% | 15% | 15% (5%-10%) | 30% |
| Week8 | Week12 | Continuous | Week2-week 12 | Week 16 |

** *Project Assessment Criteria (Rubric):*

| PART I: PROJECT APPEARANCE | EXCELLENT (3) | ACCEPTABLE (2) | POOR (1) |
|---|---|---|---|
| Good quality of illustrations, figures, and visuals. Diagrams, tables, etc. are used as visual aids and are labeled and titled. | | | |
| Headings and subheadings are different from the Project content (either large or bold different color … etc.). | | | |
| Correct grammar, tense and academic language is used to communicate effectively (with no spelling mistakes). | | | |
| Use of suitable fonts and consistent formatting. | | | |
| Total mark | ( /12) | | |

| PART II: PROJECT CONTENT | EXCELLENT (3) | ACCEPTABLE (2) | POOR (1) |
|---|---|---|---|
| Title effectively highlights the Project's subject matter Authors (names listed; institutional affiliations listed) | | | |
| The project purpose is stated clearly. | | | |
| Structuring: good and clear, well divided into sections, cover all project aspects, correct flow. | | | |
| Accuracy and completeness of explanations. Amount of detail is appropriate (not too detailed, not too superficial, just balanced) | | | |
| Total mark | ( /12) | | |

| PART III: KNOWLEDGE OF WORK PRESENTED | EXCELLENT (3) | ACCEPTABLE (2) | POOR (1) |
|---|---|---|---|
| Students present their project idea clearly. Eye contact, hand gestures, voice quality. | | | |
| Students show insightful knowledge about the research being presented. | | | |
| Students are willing to answer questions to the best of their ability where possible. | | | |
| Total mark | ( /9) | | |

| PART VI: PROJECT | EXCELLENT (3) | ACCEPTABLE (2) | POOR (1) |
|---|---|---|---|
| The scientific method is used; assumptions were made then evaluated through the project implementation. | | | |
| Project solves the real-life problem and can contribute to the community or industry improvement. | | | |
| The originality of research study or innovative community outreach project. | | | |
| Total mark | ( /9) | | |

| PART V: PROJECT INNOVATION AND NOVELTY (Nontraditional way of presenting data) | ( /10) |
|---|---|

| TOTAL MARK: (Part I + Part II) ×+(Part III +Part VI) ×+(Part V) ×2 | % |
|---|---|

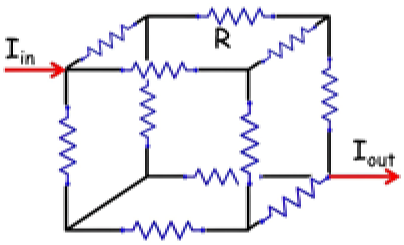
# APPENDIX 16:

## Watson and Glaser pretest question paper

### THEORY PART

1. In the cube shown below, each resistance is 1Ω, if the incoming current is 3A, find the total power consumed by the cube.

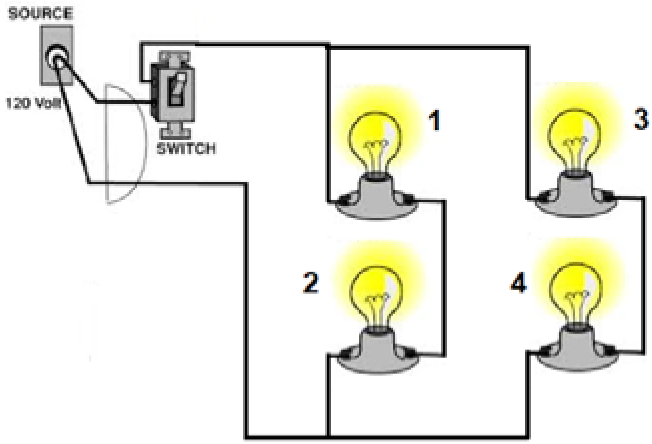
   a. 2W
   b. 2.5W
   c. 3W
   d. 4W




2. A bulb is rated at 330V- 110W. Ten such bulbs are connected to a power supply for five hours, before one bulb burns out. The rest remain on for two additional hours. Calculate the cost in AED if the rate is 30 fils/kWh. What could be a suitable rating for a protection fuse?

   a. 2.24 AED, 3 A
   b. 22.4 AED, 3 A
   c. 2.24 AED, 5 A
   d. 22.4 AED, 5 A

3. For the circuit shown below, if all lights are exactly the same, what will happen if light 1 becomes short circuited?




   a. Light 2 becomes brighter, no change on light 3 and 4.
   b. Light 2 becomes dimmer, no change on light 3 and 4.
   c. All light bulbs become brighter.
   d. All light bulbs become dimmer.

4. A piece of wire having a resistance R is cut into five equal parts.

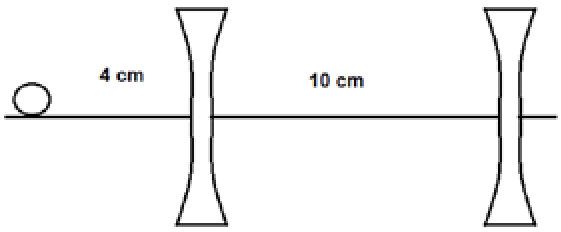
   (i) How will the resistance of each part of the wire compare with the original resistance?
   (ii) If the five parts of the wire are placed in parallel, how will the resistance of the combination compare with the resistance of the original wire?
   (i) 1/5 R
   (ii) 1/25 R

5. A 5 cm high object is placed at a distance of 25 cm from a converging lens with a focal length of 10 cm. Determine the position, size, and type of image that is produced as a result.

   a. 16.7 cm, 3.3 cm. The image formed is real and inverted.
   b. 10 cm, 5 cm. The image formed is virtual.
   c. 16.7 cm, 3.3 cm. The image formed is virtual.
   d. 10 cm, 5 cm. The image formed is real and inverted.

6. In the figure below, a pea sits at a focal point of 4 cm from a thin diverging lens (nearer). The two depicted lenses are identical and separated by 10 cm, with a common central axis. Where is the further lens' image produced? Sketch the image.

   a. 3cm to the left of the second lens.
   b. 3cm to the right of the second lens.
   c. 3cm to the left of the first lens.
   d. 3cm to the right of the first lens.

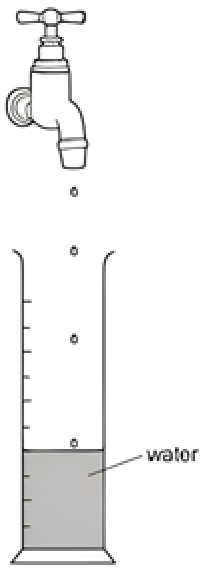


7. An inverted image is magnified by 2X when the object is placed 22 cm in front of a concave mirror. Determine the image distance and the focal length of the mirror.

    a. 20 cm
    b. 44 cm
    c. 30 cm
    d. 50 cm

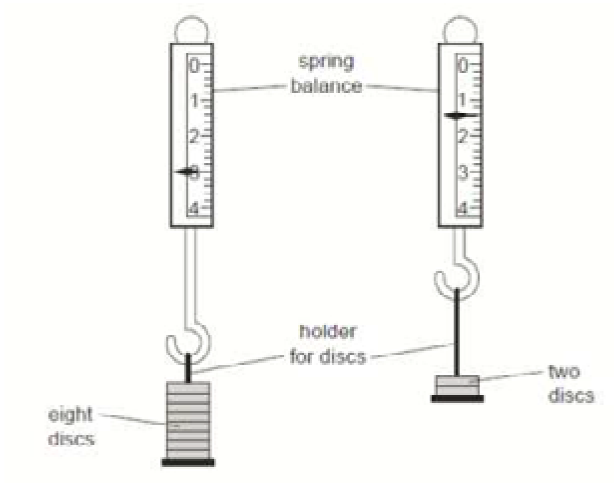
8. Tap A fills a tube in 10 minutes, while tap B fills the same tube in 20 minutes. If both taps begin filling a common tube simultaneously, how long will it take to fill that tube?

    a. 30 minutes
    b. 8 minutes 10 seconds
    c. 5 minutes 30 seconds
    d. 6 minutes 40 seconds



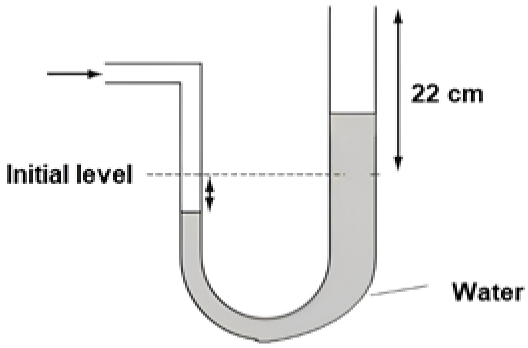

9. How many disks can the spring balance weigh?

    a. <9
    b. 9
    c. <10
    d. 10



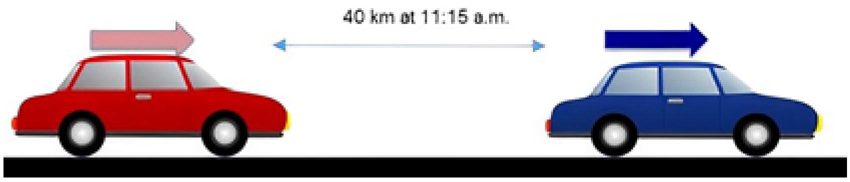
10. A non-uniform manometer shown below has two different cross section areas. The left side is 2 $cm^2$, while the right side is 3 cm2. When the tube is attached to a gas supply, the water enters the left side and fills it to 6 cm. Find the additional pressure that the gas should provide before water begins to exit the tube.

    a.
    b.
    c.
    d. None



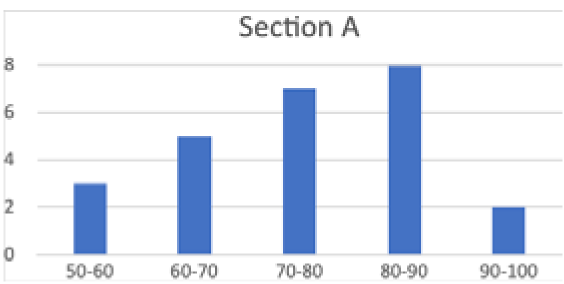

11. The initial distance between two cars is 40 km. If the speed of the red car is 60 km/h and the speed of the blue car is 40 km/h, how long will it take for the red car to pass the blue car?

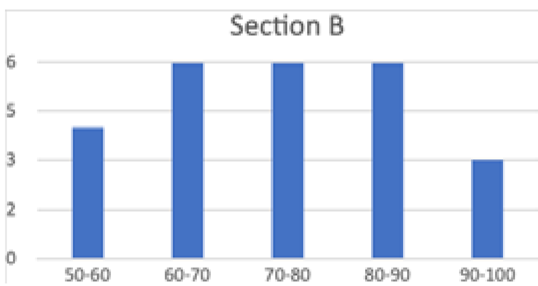
    a. 2 hours
    b. 1 hour
    c. 3 hours
    d. 2.5 hours




12. Math test results of two sections are shown below.

    a. Which section is better, justify your answer.
    b. Suggest one swap (student transfer) between section A and B to reduce the gap.



## PRACTICAL PART

Each student will be given:

A plastic ball, pencil, 30 cm wooden slider, ruler, protractor, dhow, playdoh set, 1.5m of toilet paper, adjustable plier sticks, and a stopwatch.

Students are required to set up the slider so that when the ball is placed at the top, it travels 1.0m along the toilet paper.

Each student should show his/her own calculations.

To evaluate critical thinking the following items will be considered:

- Time to achieve the task
- Proper estimation for friction coefficient
- Challenge criteria
- Reporting

### Theory part evaluation

(A) Inference
(B) Recognition of assumptions
(C) Deduction
(D) Interpretation
(E) Evaluation of arguments

| Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | A | A | B | A | A | B | A | A | A | A | A |
| B | C | C | C | B | C | D | C | C | C | B | B |
| D | | D | | C | D | C | D | D | D | D | C |
| | | | | E | E | | | | | | D |
| | | | | | | | | | | | E |

### Practical part evaluation

Testing the slider for its friction coefficient

S1. Adjusting the slider and measure its slope.
S2. Get the component of the ball weight along the slider.
S3. Using the stopwatch to measure ball travel time on slider.

S4. Get the normal force.
S5. Obtain the friction force of the slider.
S6. Estimate the friction coefficient of the slider

## Testing the toilet paper for its friction coefficient

S7. Adjusting the slider and measure its slope
S8. Get the component of the ball weight along the slider.
S9. Using the stopwatch to measure ball travel time on both slider and toilet paper.
S10. Measure the distance travelled on the toilet paper.
S11. Get the normal force on the toilet paper.
S12. Estimate the friction coefficient of the toilet paper.

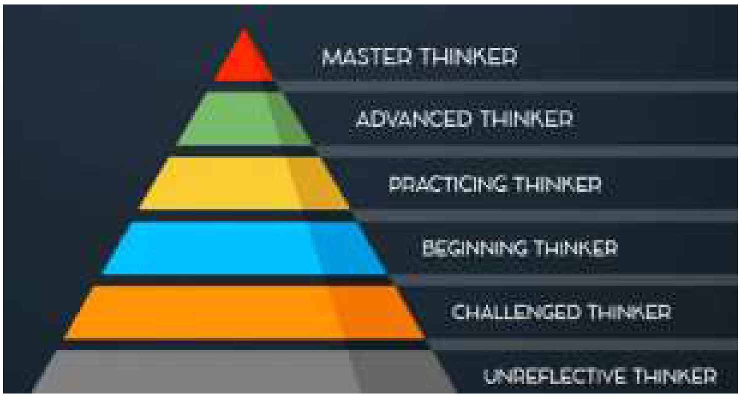
## Design calculations

S13. Use the previously estimated friction to calculate the proper slope for the slider that makes the ball travel 1m on the toilet paper.

| S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | S13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | A | A | B | B | D | A | A | A | B | B | D | A |
| B | B | B | C | C | E | B | B | B | C | C | E | B |
| | C | | D | D | | | C | | D | D | | C |
| | D | | E | E | | | D | | E | E | | D |
| | E | | | | | | E | | | | | E |

## Score-Level Mapping

- Level 1: 90%-100%
- Level 2: 81%-90%
- Level 3: 61%-80%
- Level 4: 41%-60%
- Level 5: 30%-40%
- Level 6: <30%



# APPENDIX 17:

## Watson and Glaser Post-test question paper

### CT- TEST

#### Test instructions

- This test consists of 13 pages including this cover page.
- Starting from the next page, one question appears on each page.
- You are required to show detailed steps for each question and an elaboration on your method to solving each problem.
- Wherever choices are given, circle the choice that best matches your answer.
- You are allowed to use any of the following calculators.

fx-991ES PLUS · fx-991ES PLUS · fx-570EX · fx-350EX

#### Student details

| | |
|---|---|
| Name: | |
| ID: | |
| Date of birth: | |

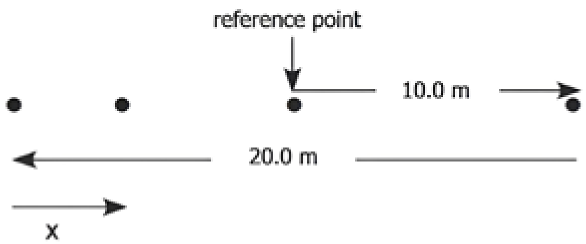
#### This part is to be used by grader only

| Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |

Grader name and signature

Reviewer name and signature

13. A body moves 10 m to the right of a given starting point, in a time of 1 s. It then moves 20 m to the left in a time of 3 s. Finally, it moves (x) m to the right in a time of 1 s. The diagram below represents this motion.

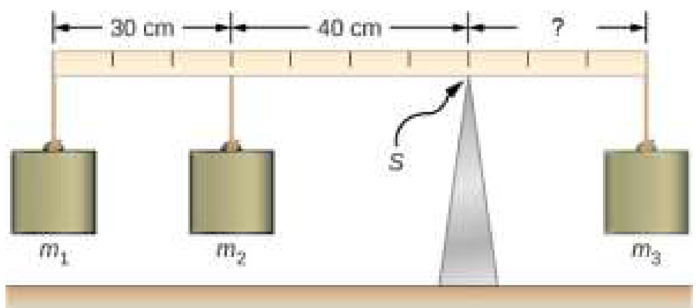



If the average speed is 7 m/s then x is:

a. 5 m
b. 2 m
c. 6 m
d. 4 m

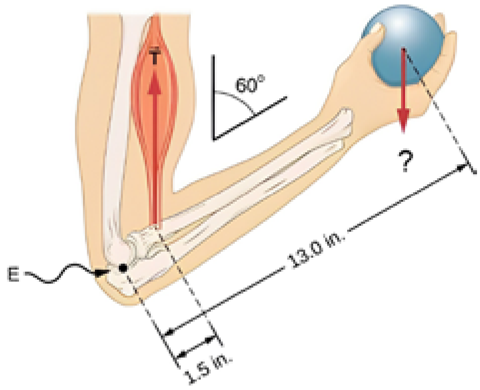
14. Three masses are attached to a uniform meter stick, as shown below. The mass of the meter stick is 150g and the masses to the left of the fulcrum are m1=50g and m2=75g. At what distance should the mass m3=317g that balances the system be placed?

a. 20 cm
b. 25 cm
c. 30 cm
d. 35 cm



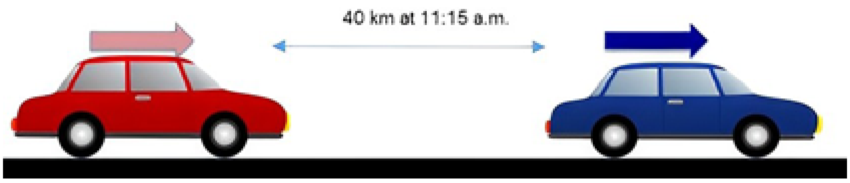

15. A weightlifter holds a ball, as depicted below. His forearm is positioned at =60° with respect to his upper arm. The forearm is supported by the contraction of the biceps muscle, which causes a torque to be applied to the elbow. If the tension in the biceps acts along the vertical direction given by gravity, what ball weight will induce a tensile force of 433.3 lbs within the muscle?

e. 30 lbs
f. 40 lbs
g. 50 lbs
h. 60 lbs



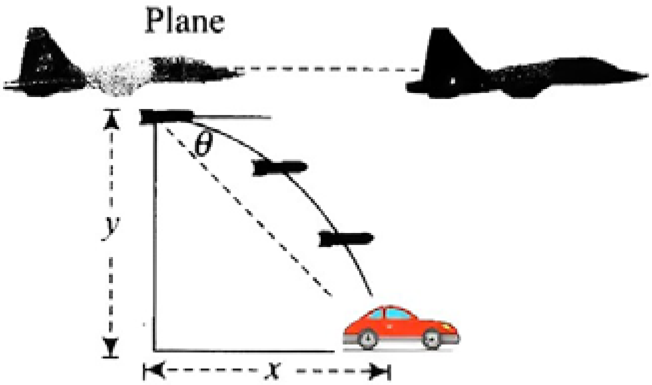
16. Two cars (A and B) are moving in the same direction in a straight line. Car A moves at a constant speed of 60 km/h. At 11:15, car A was 40 km a head of car B. At what speed does car B have to move, for both cars to be level by 12:30?

e. 92 km/h
f. 90 km/h
g. 85 km/h
h. 88 km/h

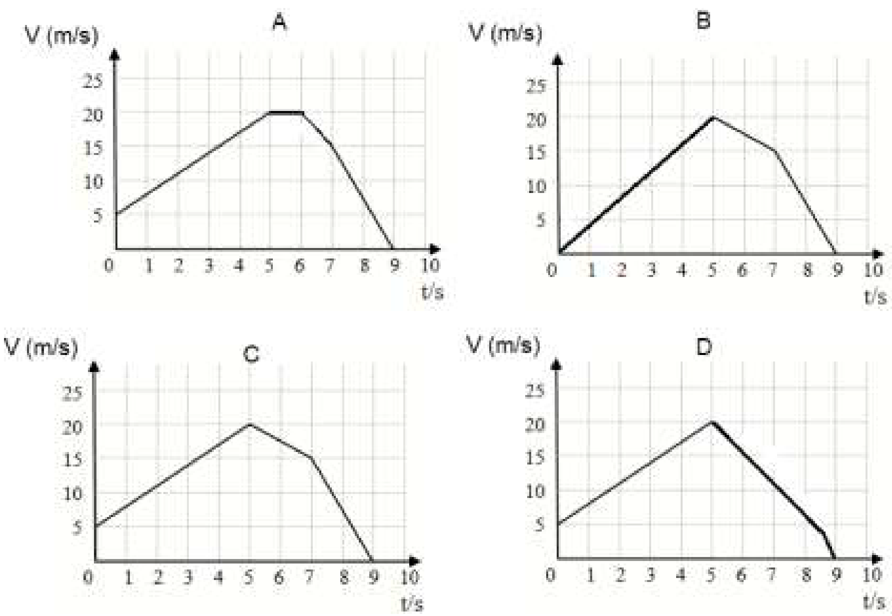



17. A fighter plane flying at a constant speed of 720 km/h targets an object moving in a straight line at a speed of 100 km/h. If the plane is flying at a height of 1.5 km, and the distance between the car, plane, and target was initially 3.647 km, at what angle should a bomb be thrown from the plane for it to land on the target.

a. 12 °
b. 23 °
c. 42 °
d. 53 °

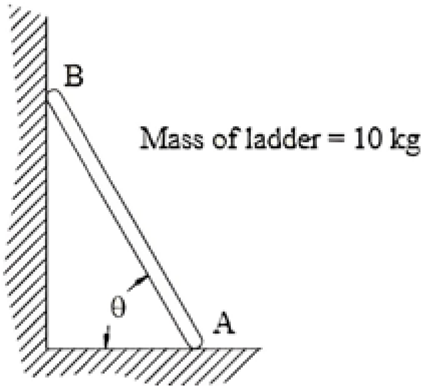



18. Four objects are moving in a straight line. The speed of each one varies with time, as depicted below. Which object travels the furthest distance?



19. A uniform ladder is 2 m long and the wall at B is smooth. If the coefficient of static friction at A is A = 0.2, determine the smallest angle for which the ladder can remain in the position depicted below.

a. 23 °
b. 32 °
c. 49 °
d. 60 °




20. A squirrel runs along a fence. Mr. Jensen, curious about squirrel velocities, has wisely observed at which fence post the squirrel is located, at one-second intervals. After the squirrel has run away, Mr. Jensen measures the spacing between two adjacent fence posts to be 5 ft.

| Time: | 0.0 sec | 1.0 sec | 2.0 sec | 3.0 sec | 4.0 sec | 5.0 sec | 6.0 sec |
|---|---|---|---|---|---|---|---|
| Distance: | 0.0 ft | 5.0 ft | 15 ft | 25 ft | 35 ft | 55 ft | 60 ft |

Part (a)

Do you need all 7 measurements to determine the squirrel's average velocity over the entire 6 seconds, or could you do it with only two? Which two would you use? What is the average velocity?

Part (b)

During which time interval will the squirrel achieve the maximum acceleration/deceleration? What is the maximum acceleration/deceleration?

21. A car uses 12 gallons of gasoline and travels a total distance of 290 miles. The car's fuel efficiency is 25 miles per gallon on the highway, and 20 miles per gallon in the city. The variable h will represent the number of gallons used on the highway. Which equation could be used to find h?

a. 25h+ 20(12 –h) = 290
b. 20h+ 25(12 –h) = 290
c. 25h+ 20(12 +h) = 290
d. 20h+ 25(12 +h) = 290

22. Ali has a certain number of apples and a certain number of paper boxes. If he places apples in each box, one box will be left over, if he places 7 apples in each box one apple will be left over. How many apples, and how many paper boxes, does Ali have?

23. A man invests $3000 into the stock market, and after a year, his total balance grows to $3300. He withdraws just $100, and has a balance of $3200 after the second year. If the profit rate remains the same for 5 years, and the man withdraws $100 each year, what will the total profit be, by the end of year 5, including all withdrawn money?

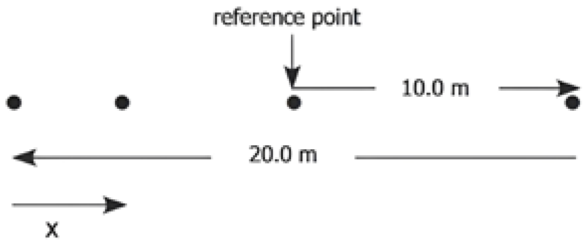
24. After taking a cough suppressant, an amount: A, in mg, remains in the body. The calculation is represented by: , where  is given in hours. While the remaining amount of a certain pain killer is represented by:. If a patient takes a cough suppressant one hour after ingesting the pain killer, at what time will the amounts of A and B in his body become the same? Assume the pain killer was obtained at 10:00.

# APPENDIX 18:

## Watson and Glaser Post-test answers

### THEORY PART

25. A body moves 10 m to the right of a given starting point, in a time of 1 s. It then moves 20 m to the left in a time of 3 s. Finally, it moves (x) m to the right in a time of 1 s. The diagram below represents this motion.

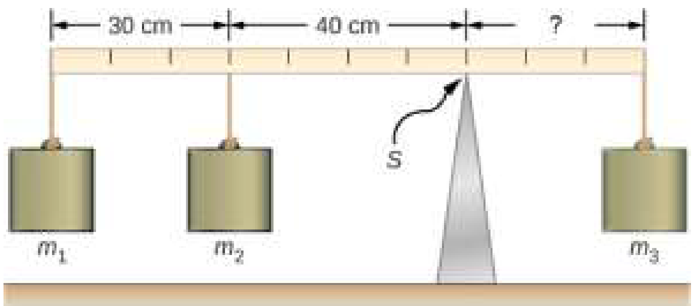



If the average speed is 7 m/s then x is:

e. 5 m
f. 2 m
g. 6 m
h. 4 m

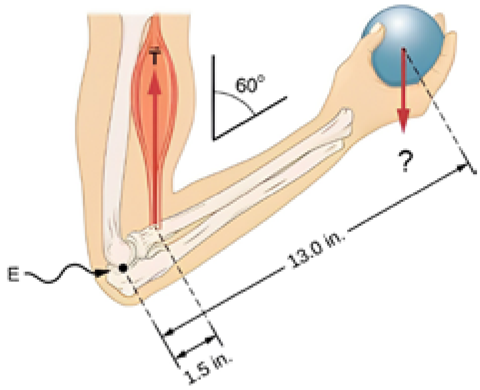
26. Three masses are attached to a uniform meter stick, as shown below. The mass of the meter stick is 150g and the masses to the left of the fulcrum are m1=50g and m2=75g. At what distance should the mass m3=317g that balances the system be placed?

e. 20 cm
f. 25 cm
g. 30 cm
h. 35 cm



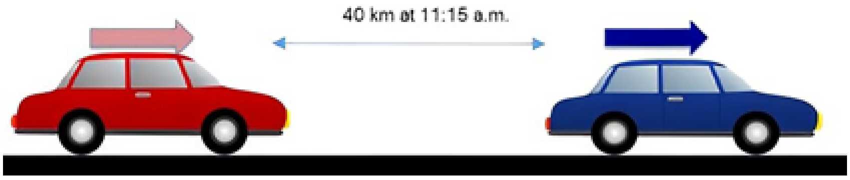
27. A weightlifter holds a ball, as depicted below. His forearm is positioned at =60˚ with respect to his upper arm. The forearm is supported by the contraction of the biceps muscle, which causes a torque to be applied to the elbow. If the tension in the biceps acts along the vertical direction given by gravity, what ball weight will induce a tensile force of 433.3 lbs within the muscle?

    i. 30 lbs
    j. 40 lbs
    k. 50 lbs
    l. 60 lbs



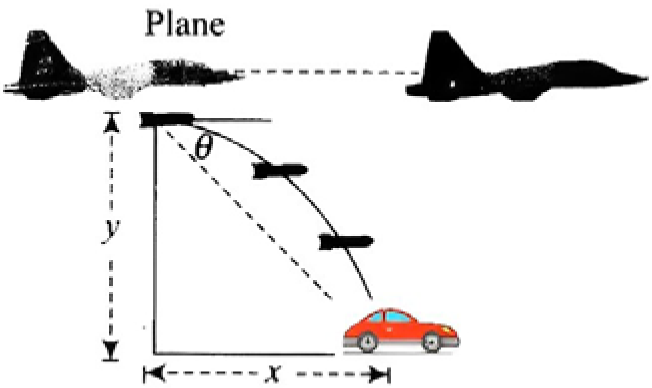

28. Two cars (A and B) are moving in the same direction in a straight line. Car A moves at a constant speed of 60 km/h. At 11:15, car A was 40 km a head of car B. At what speed does car B have to move, for both cars to be level by 12:30?

    i. 92 km/h
    j. 90 km/h
    k. 85 km/h
    l. 88 km/h

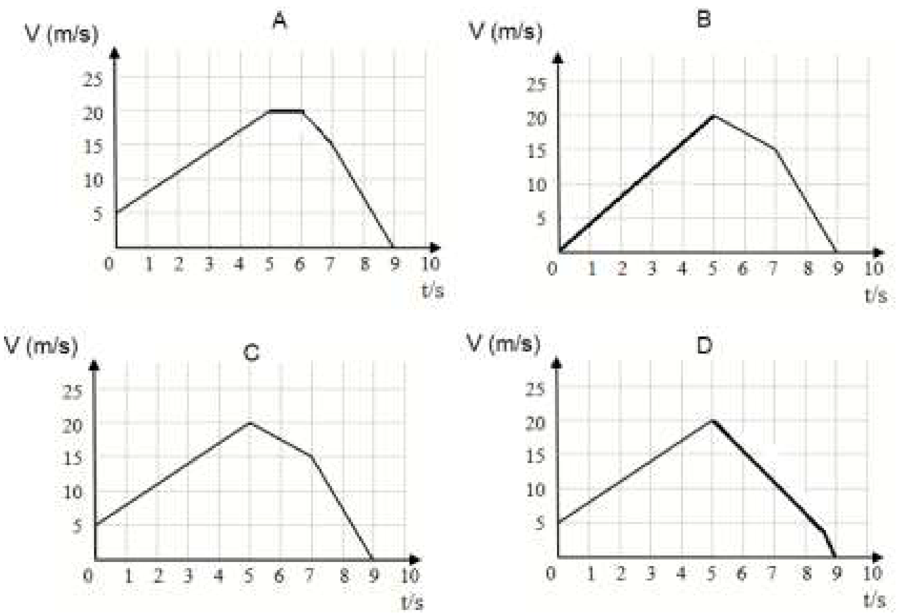



m. A fighter plane flying at a constant speed of 720 km/h targets an object moving in a straight line at a speed of 100 km/h. If the plane is flying at a height of 1.5 km, and the distance between the car, plane, and target was initially 3.647 km, at what angle should a bomb be thrown from the plane for it to land on the target.

    e. 12 ˚
    f. 23 ˚
    g. 42 ˚
    h. 53 ˚

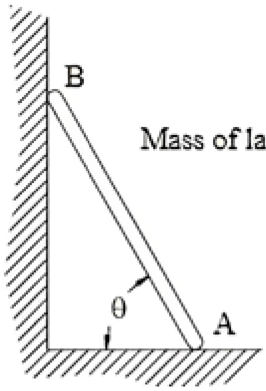


29. Four objects are moving in a straight line. The speed of each one varies with time, as depicted below. Which object travels the furthest distance? (answer: A)

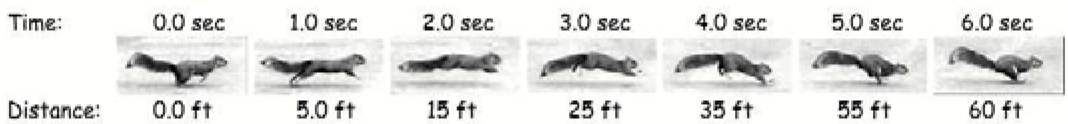



30. A uniform ladder is 2 m long and the wall at B is smooth. If the coefficient of static friction at A is A = 0.2, determine the smallest angle for which the ladder can remain in the position depicted below.

e. 23 ˚
f. 32 ˚
g. 49 ˚
h. 60 ˚




31. A squirrel runs along a fence. Mr. Jensen, curious about squirrel velocities, has wisely observed at which fence post the squirrel is located, at one-second intervals. After the squirrel has run away, Mr. Jensen measures the spacing between two adjacent fence posts to be 5 ft.



Part (a)

Do you need all 7 measurements to determine the squirrel's average velocity over the entire 6 seconds, or could you do it with only two? Which two would you use? What is the average velocity?

No,
Two only, [0, 6]
10 ft. /sec

Part (b)

During which time interval will the squirrel achieve the maximum acceleration/deceleration? What is the maximum acceleration/deceleration?

Acceleration [4, 5]/ Acceleration [5, 6]
Acceleration 10 m/s, Acceleration 15

32. A car uses 12 gallons of gasoline and travels a total distance of 290 miles. The car's fuel efficiency is 25 miles per gallon on the highway, and 20 miles per gallon in the city. The variable h will represent the number of gallons used on the highway. Which equation could be used to find h?

e. 25h+ 20(12 –h) = 290
f. 20h+ 25(12 –h) = 290
g. 25h+ 20(12 +h) = 290
h. 20h+ 25(12 +h) = 290

33. Ali has a certain number of apples and a certain number of paper boxes. If he places apples in each box, one box will be left over, if he places 7 apples in each box one apple will be left over. How many apples, and how many paper boxes, does Ali have?

| | |
|---|---|
| Boxes | 9 |
| Apples | 64 |

34. A man invests $3000 into the stock market, and after a year, his total balance grows to $3300. He withdraws just $100, and has a balance of $3200 after the second year. If the profit rate remains the same for 5 years, and the man withdraws $100 each year, what will the total profit be, by the end of year 5, including all withdrawn money?

Answer: 1721

35. After taking a cough suppressant, an amount: A, in mg, remains in the body. The calculation is represented by: , where  is given in hours. While the remaining amount of a certain pain killer

is represented by:. If a patient takes a cough suppressant one hour after ingesting the pain killer, at what time will the amounts of A and B in his body become the same? Assume the pain killer was obtained at 10:00.

Answer: 11:46

## PRACTICAL PART

Each student will be given:

A plastic ball, pencil, 30 cm wooden slider, ruler, protractor, dhow, playdoh set, 1.5m of toilet paper, adjustable plier sticks, and a stopwatch.

Students are required to set up the slider so that when the ball is placed at the top, it travels 1.0m along the toilet paper.

Each student should show his/her own calculations.

To evaluate critical thinking the following items will be considered:

- Time to achieve the task
- Proper estimation for friction coefficient
- Challenge criteria
- Reporting

### Theory part evaluation

(C) Inference
(D) Recognition of assumptions
(C) Deduction
(D) Interpretation
(E) Evaluation of arguments

| Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | A | A | B | A | A | B | A | A | A | A | A |
| C | B | C | C | B | C | D | B | C | B | C | C |
| D |  | D | D | C | D |  | C | D | C | D | D |
|  |  |  |  | E | E |  | D |  |  |  |  |
|  |  |  |  |  |  |  | E |  |  |  |  |

## Practical part evaluation

Testing the slider for its friction coefficient

S1. Adjusting the slider and measure its slope
S2. Get the component of the ball weight along the slider
S3. Using the stopwatch to measure ball travel time on slider
S4. Get the normal force
S5. Obtain the friction force of the slider
S6. Estimate the friction coefficient of the slider

Testing the toilet paper for its friction coefficient

S7. Adjusting the slider and measure its slope
S8. Get the component of the ball weight along the slider
S9. Using the stop watch to measure ball travel time on both slider and toilet paper
S10. Measure the distance travelled on the toilet paper
S11. Get the normal force on the toilet paper
S12. Estimate the friction coefficient of the toilet paper

Design calculations

S13. Use the previously estimated friction to calculate the proper slope for the slider that makes the ball travel 1m on the toilet paper

| S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | S13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | A | A | B | B | D | A | A | A | B | B | D | A |
| B | B | B | C | C | E | B | B | B | C | C | E | B |
| | C | | D | D | | | C | | D | D | | C |
| | D | | E | E | | | D | | E | E | | D |
| | E | | | | | | E | | | | | E |

## Score-Level Mapping

- Level 1: 90%-100%
- Level 2: 81%-90%
- Level 3: 61%-80%
- Level 4: 41%-60%
- Level 5: 30%-40%
- Level 6: <30%

# APPENDIX 19:

## Rubric for pre-test theoretical and practical questions

### 1. THEORETICAL PRE-TEST (Q)

There are (12) questions, which will measure student's critical thinking skills based on Watson – Glaser Critical Thinking Appraisal – UK Edition as following:

(E) Inference
(F) Recognition of assumptions
(C) Deduction
(D) Interpretation
(E) Evaluation of arguments

The table below shows each question and which skill it will measure

| Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | A | A | B | A | A | B | A | A | A | A | A |
| B | C | C | C | B | C | D | C | C | C | B | B |
| D | | D | | C | D | C | D | D | D | D | C |
| | | | | E | E | | | | | | D |
| | | | | | | | | | | | E |

### 1. PRACTICAL PRE-TEST (S)

In this part (13) will be given to students and they are measuring the same skills.

#### 1.1. Testing the slider for its friction coefficient

S1. Adjusting the slider and measure its slope
S2. Get the component of the ball weight along the slider
S3. Using the stop watch to measure ball travel time on slider
S4. Get the normal force
S5. Obtain the friction force of the slider
S6. Estimate the friction coefficient of the slider

## 1.2. Testing the toilet paper for its friction coefficient

S7. Adjusting the slider and measure its slope
S8. Get the component of the ball weight along the slider
S9. Using the stop watch to measure ball travel time on both slider and toilet paper
S10. Measure the distance travelled on the toilet paper
S11. Get the normal force on the toilet paper
S12. Estimate the friction coefficient of the toilet paper

## 1.3 Design calculations

S13. Use the previously estimated friction to calculate the proper slope for the slider that makes the ball travel 1m on the toilet paper

The table below shows each question and which skill it will

| S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | S13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | A | A | B | B | D | A | A | A | B | B | D | A |
| B | B | B | C | C | E | B | B | B | C | C | E | B |
| | C | | D | D | | | C | | D | D | | C |
| | D | | E | E | | | D | | E | E | | D |
| | E | | | | | | E | | | | | E |

### Score-Level Mapping

- Level 1: 90%-100%
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- Level 3: 61%-80%
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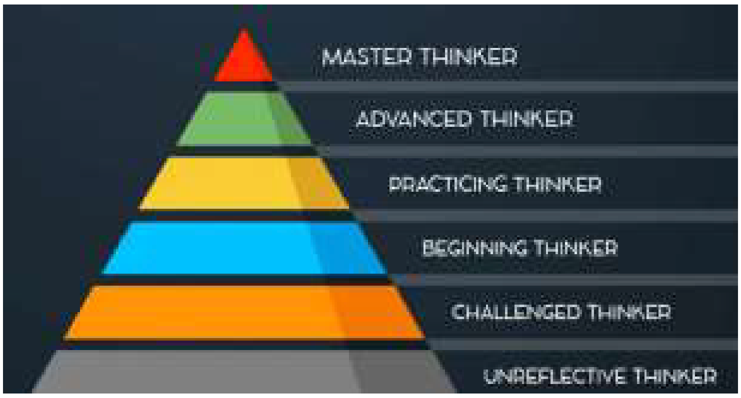
- Level 5: 30%-40%
- Level 6: <30%



# APPENDIX 20:

**Skills for Life – Snail Car prototype**

## DAY 1: SNAIL CAR PROJECT

## DAY 2: SNAIL CAR PROJECT

TESTING MATERIALS

THE PROPERTIES OF MATERIALS and their everyday uses

Understanding how materials behave in their natural state and under certain conditions will help them to understand why objects are made of specific materials.

A material can be described in a variety of ways, for example:

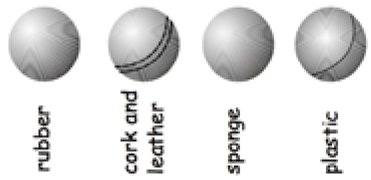
1. Hardness - Resistance to scratching and pressure
2. Strength - Amount of force needed to break a material, usually by pushing or pulling down.
3. Toughness - Resistance to breaking by cracking, opposite to 'brittle'
4. Stiffness - Amount of force needed to change the shape of a material
5. Elasticity - Ability to return its original shape when a force is removed
6. Plasticity - Ability to retain the new shape when a force is removed
7. Absorbency - Ability of a material to soak up a liquid

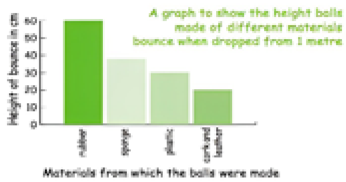
SKILLS: Recognizing and carrying out a fair test, repeating a procedure.

Measuring length with a degree of accuracy.
Constructing a bar graph.
Careful observation.
Working cooperatively.
Recording carefully.
Use of ICT for graph drawing.

(a) Balls are made from a variety of materials. Investigate this topic by answering the questions below.

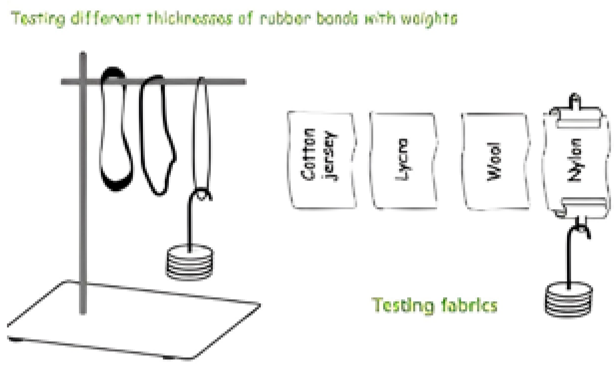
Which is the bounciest ball? Look at balls made from a variety of materials and discuss the different uses and properties, including sizes.




(b) Elastic bands are discussed below. Investigate this topic by answering the questions.

Carry out this experiment on the floor. Hold the band and weight against a ruler to see which stretches the most.

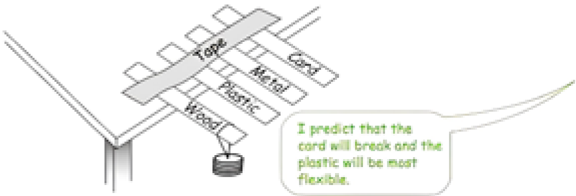



(c) Stretchy materials

Strips of fabric can have weights hung onto them. What length is the fabric at the start? To what length does it stretch? What length does it return to? Use bulldog clips to support the weights or cut a hole in the fabric to hang the weights through.

(d) Flexibility

Different materials can be tested e.g. identical lengths of wood, plastic, metal (use rulers) and card to investigate how much they will bend by hanging weights from string onto the end or samples, use a light weight and investigate 'which material bends the most using a 100g weight?




## DAY 3

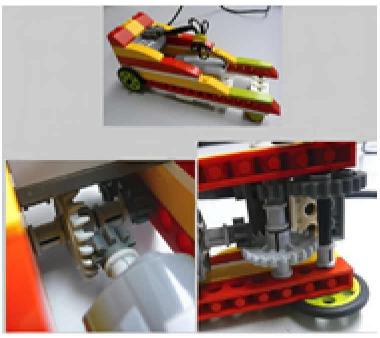
Learning Objectives:

To learn to calculate the speed of the car using distance time relationship and see the effect of friction on the speed of the car.

Procedure and points to remember:

1. Run your own cars.
2. Figure out how you can increase the friction in your cars.
3. You may use various things (example, rubber bands) to increase the friction.
4. Your snail must move forward at a constant pace during the race, though its forward motion can be very slow.
5. In other words, no stopping, no turning, and no backing up.
6. You must calculate the slowdown of your snail by recording distance and time in observation table.
7. You need to calculate speed by using the formula.

Observation Table:



| S. NO. | DISTANCE (D) IN METERS | TIME(T) IN SECONDS | SPEED(V) IN M/S |
|---|---|---|---|
| 1. | | | |
| 2. | | | |
| 3. | | | |

Average speed=______________ m/s

ACTIVITY SHEET:

Match The following: Write down the correct number in the space provided in the third column.

| | | | |
|---|---|---|---|
| 1. | Speed | A machine consisting of two or more simple machines operating together, as a wheelbarrow consisting of a lever, axle, and wheel. | |
| 2. | Simple machine | Distance travelled by an object in a given timeframe. | |
| 3. | Compound machine | A simple machine is a mechanical device that changes the direction or magnitude of a force. | |
| 4. | Friction | The length of the space between two points. | |
| 5. | Distance | Opposing force between two surfaces in contact. | |

## Science Investigation Sheet

Topic: Forces and Movement

**My Investigation**: FRICTION

Today I want to find out if the __________ of the ground affects the __________ a ______ can travel before it _________.

| | | | |
|---|---|---|---|
| stops | surface | distance | car |

**My Plan**: What am I going to do?

**I am going to roll a car down a slope onto 4 different surfaces.**

**Surface 1**: ____________________

**Surface 2**: ____________________

**Surface 3**: ____________________

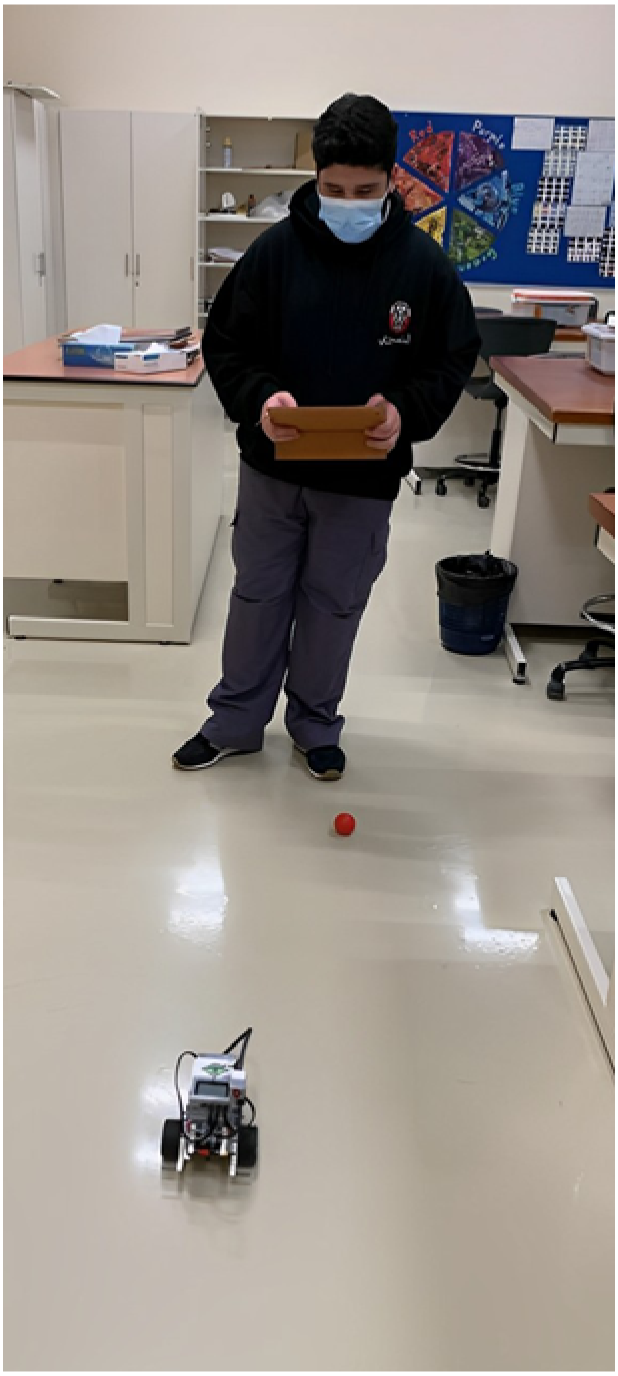
**Surface 4**: ____________________

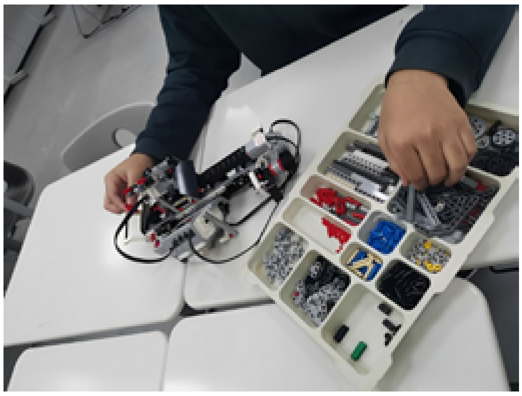
**Evaluation:** How can we decrease the friction? Tick the correct option **Ö**

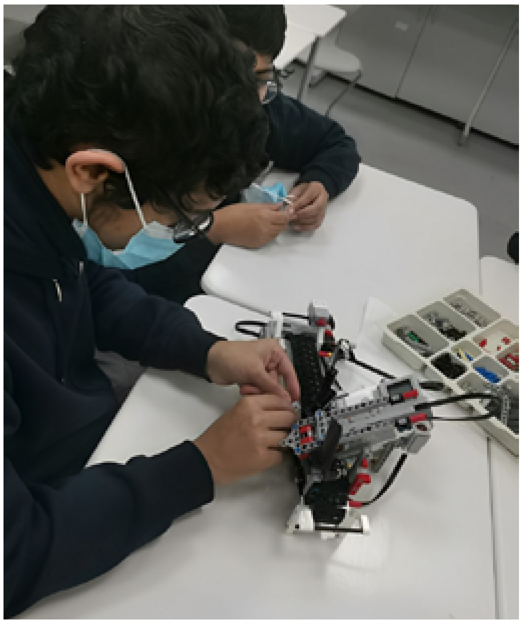
| | |
|---|---|
| Lubrication | |
| Heating | |
| Streamlining | |
| Throwing sand on surface | |

# APPENDIX 21:

**Photos of students during the construction phase of the snail car**







# APPENDIX 22:

## Student interview transcript example

Unknown Speaker 0:52
I hope you had fun with your snail car. I'll be asking you a series of questions about the PBL activity. D Did you find a need for a snail car in the real world?

Unknown Speaker 2:47
Its an idea to help for designing a very challenge project and it might partially used in the real world for example mines detector robot , advance mechanical gearbox and advance electrical/electronic circuits. Basically, it was like you were making your own thing as an engineer or scientist

Unknown Speaker 1:02
I can see you like engineering. So question two is not about engineering. So, tell me how did you feel about the STEM PBL experiment?

Unknown Speaker 2:18
For me, it was a fun way to learn. I like it when you start with something you don't really know what you're making, but at the end you build something you really like." It was a very great since we focus in one output idea and workout in each class with different subject to come up with different solutions. "We did snail car in groups instead of the teacher helping us to do it.

Unknown Speaker 0:39
Okay. So question three, was your snail car successful?

Unknown Speaker 0:25
Yes with limited output.

Unknown Speaker 0:52
Thank you. Now my last question to you, What did you learn during the STEM PBL experiment?

Unknown Speaker 2:43
It helps you with your education, and you get to do things you wouldn't normally get to do. STEM is fun for me. I don't get to do that every day. I learned to convert all knowledge with different subjects into a practical ordinated application via working in teamwork and building a prototype to achieve the required objectives.

Unknown Speaker 0:52
Thank you for today and your time. That's the end of the interview, and I'll stop recording now.

Transcribed by https://otter.ai

# APPENDIX 23:

## Teacher Interview transcript example

Unknown Speaker 0:02
I'll be asking you a series of questions about the PBL activity of the students building the snail car protopty. The first question is, Did you consider the STEM intervention successful?

Unknown Speaker 0:47
Yes, the intervention was in my opinion successful. I have explained what the students should do and interested to know if the intervention would test the students skills and knowledge. I observed how the boys enjoyed working on their prototype.

Unknown Speaker 0:52
Okay. So question two, which factors contributed to the success of the intervention?

Unknown Speaker 1:01
I would say knowledge and skills, definitely their critical thinking, as to how they were asking quesions and tried to figure out the instructions. I would also say that their problem solving skills also improved.

Unknown Speaker 0:52
Okay. So question three, did you notice differences between students in the experimental and students in the control group

Unknown Speaker 1:54
There were clear differences between experimental and the control group. I think is was probably with how we explained the guidelines between the one group of boys. That could be the reason why I think there were differences between the two groups.

Unknown Speaker 1:02
Thank you. Now my next question to you, could you identify any challenges, and how did the students adapt to such challenges? I specifically think about when all the UAE schools went online in March 2020.

Unknown Speaker 2:43
The main challenge was gathering students in the school for doing projects, as school was on online during covid-19 pandemic where we success running the theoretical part online and the practical in (15) classrooms with capacity of five students in. The other challenge was working in groups as this concept is new to my students it was hard in the beginning but they used to it as they become familiar with each other.

Unknown Speaker 0:50
Could you tell me, did you find that students developed their critical thinking skills during the intervention?

Unknown Speaker 1:51
Yes, student's critical thinking was developing during the intervention phase. I could see how keen they were to finish the snail car. The boys were happy to show me each part of their car development.

Unknown Speaker 0:59
Thank you. All right. The next question I want to ask is do you consider project-based learning effective in a STEM curriculum?

Unknown Speaker 2:00
Yes, I definitely believe that project based learning is effective in a STEM curriculum as students attitude is improved to words, learning and understanding.

# APPENDIX 24:

## Peer-reviewed article

education sciences

MDPI

*Systematic review*

# Gendered STEM: A Systematic Review and Applied Analysis of Female Participation in STEM in the United Arab Emirates

**Ibrahim Alzaabi[1,]*, Antonia Ramírez-García [1] and Manuel Moyano [2]**

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* Correspondence: sc2alali@uco.es; Tel.: +971 504445741

**Abstract:** The present study aims to identify potential barriers that women in the United Arab Emirates might face if they pursue careers in science, technology, engineering, and mathematics (STEM). For this purpose, a systematic review and subsequent applied analysis of the UAE context was developed. The systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and PRISMA Extension for Scoping Reviews. The review was performed on EBSCO, ProQuest, Wiley Online Library, Gale, Taylor and Francis Online, SAGE Complete, and JSTOR. The initial database search yielded 168 articles. Following a review of the corresponding abstracts, eight full-text articles that fulfilled the inclusion criteria were selected. The results obtained are discussed in the context of the UAE and help inform policy proposals and future research lines to strengthen the involvement of women in STEM careers. The study found that while women in the UAE have greater access to education in engineering and STEM fields, women's employment prospects in these sectors remain fraught.

**Citation:** Alzaabi, I.; Ramírez García, A.; Moyano, M. Gendered STEM: A Systematic Review and Applied Analysis of Female Participation in STEM in the United Arab Emirates. *Educ. Sci.* **2021**, *11*, x. https://doi.org/10.3390/xxxxx

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UNIVERSIDAD DE CÓRDOBA

Doctoral thesis presented by

**Ibrahim Khalaf Saleh Khalaf Alzaabi**

to qualify for the title of doctor

University of Cordoba

**TÍTULO DE LA TESIS:**

Using a project-based learning approach to foster interest in STEM subjects and the development of critical thinking in a vocational school in the UAE.

Utilización de un enfoque de aprendizaje basado en proyectos para fomentar el interés por las materias STEM y el desarrollo del pensamiento crítico en una escuela de formación profesional de los EAU.

**DOCTORANDO/A:** IBRAHIM KHALAF SALEH KHALAF ALZAABI

## INFORME RAZONADO DEL/DE LOS DIRECTOR/ES DE LA TESIS

(se hará mención a la evolución y desarrollo de la tesis, así como a trabajos y publicaciones derivados de la misma).

La tesis realizada por el doctorando se ha llevado a cabo a lo largo de cuatro años de trabajo en los que ha compaginado su profesión con la investigación.

Durante este tiempo la tutorización se ha realizado básicamente online debido a su lugar de residencia en Emiratos Árabes, aunque en algunas ocasiones se ha llevado a cabo de forma presencial. Este proceso ha sido fluido en el tiempo y el doctorando ha demostrado interés e iniciativa personal en el desarrollo de la investigación.

En cuanto a la tesis que se presenta, esta incluye un marco teórico actualizado y acorde al tema de investigación, destacando la importancia de visibilizar e integrar las asignaturas de Ciencias, Tecnología, Ingeniería y Matemáticas (STEM, por sus siglas en inglés) en el currículum. Asimismo, insiste en la necesidad de implementar nuevas metodologías docentes en el proceso de enseñanza y aprendizaje de estas asignaturas, entre ellas el Aprendizaje Basado en Proyectos (ABP) como promotora del pensamiento crítico.

La investigación ha contado con el permiso del Ministerio de Educación emiratí e incluye dos estudios, uno de naturaleza cuantitativa y otro de carácter cualitativo.

El estudio cuantitativo ha seguido un diseño cuasi-experimental (pretest-postest, con grupo experimental y grupo control) y trataba de determinar un incremento del interés por asignaturas STEM y un aumento del pensamiento critico en aquellos estudiantes que tuvieron un proceso de enseñanza y aprendizaje sustentado en el ABP.
La muestra ha estado constituida por 150 estudiantes (75 para el grupo control y 75 para el grupo experimental).

Las pruebas estadísticas realizadas en torno a los datos obtenidos son pertinentes, dando respuesta a los objetivos y las hipótesis planteadas, permitiendo una discusión ajustada de los resultados y su argumentación en base al marco teórico redactado.

La tesis finaliza con unas conclusiones generales, una serie de limitaciones detectadas y una propuesta de futuras líneas de investigación.

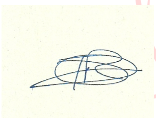
Fruto de la tesis doctoral se ha publicado un artículo y se espera que se lleven a cabo otras publicaciones posteriores a la defensa de esta. De igual forma, el doctorando ha participado en acciones formativas desarrollas por la Escuela de Doctorado de la Universidad de Córdoba, como las jornadas congresuales, así como otras que se han considerado pertinentes a lo largo del proceso.
El artículo publicado ha sido el siguiente:

ALZAABI, I., RAMÍREZ-GARCÍA, A. Y MOYANO, M. (2021). Gendered STEM: A Systematic Review and Applied Analysis of Female Participation in STEM in the United Arab Emirates. *Education Sciences, 11* (573), 1-14. https://doi.org/10.3390/educsci11100573 Indexada: SCOPUS (2020): SNIP: 1.204; SJR: 0.453; Cite Score: 2.1; Posición: 428 de 1319 (percentil 67).

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba, 2 de mayo de 2024

Firma de los directores



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Fdo.: Antonia Ramírez García

Fdo: Manuel Moyano Pacheco

RESUMEN EN ESPAÑOL

UNIVERSIDAD
D CÓRDOBA

# Using a project-based learning approach to foster interest in STEM subjects and the development of critical thinking in a vocational school in the UAE

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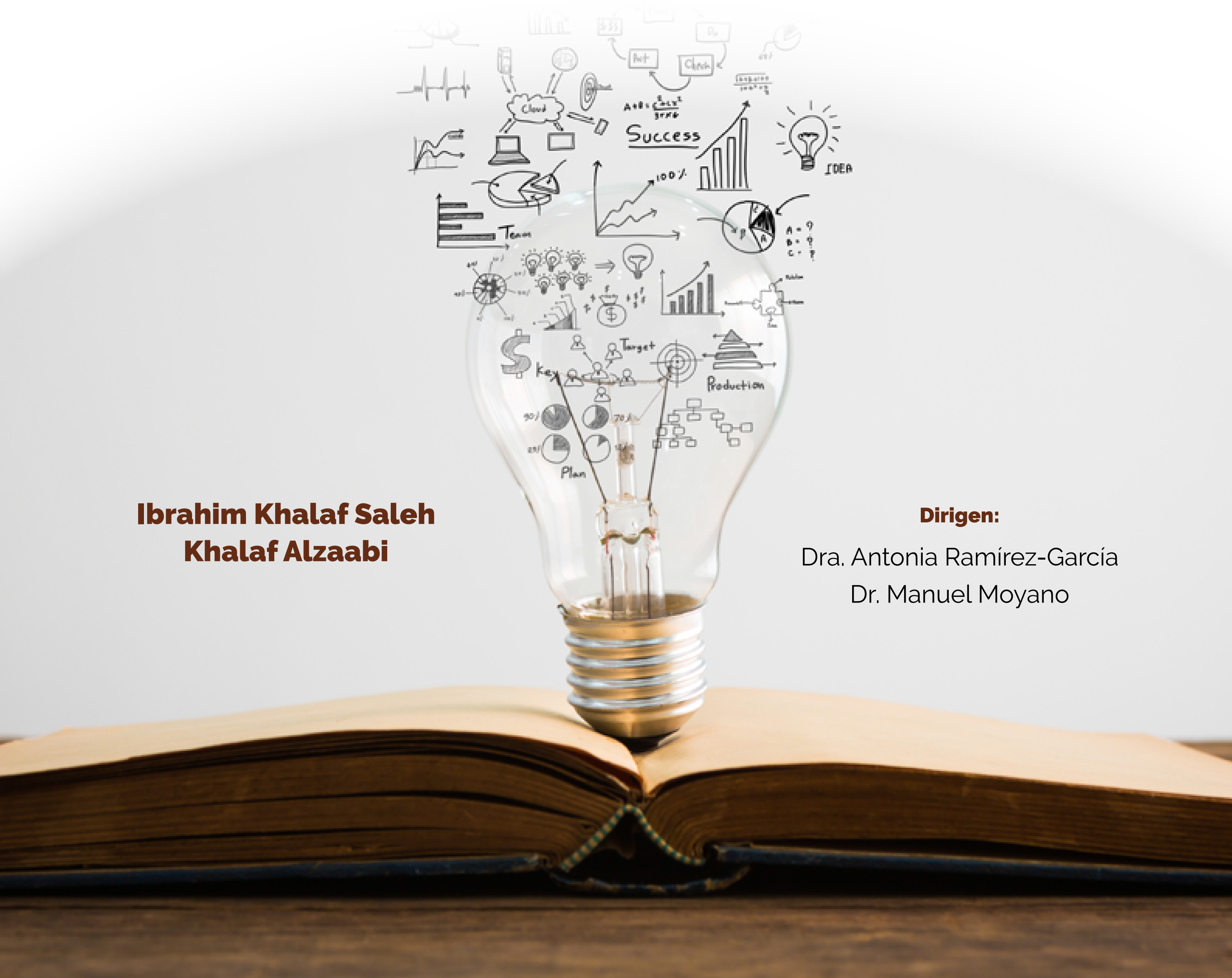


**Ibrahim Khalaf Saleh Khalaf Alzaabi**

**Dirigen:**

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Dr. Manuel Moyano

UNIVERSIDAD
D CÓRDOBA

# ÍNDICE

# RESUMEN

¿Tienden los estudiantes del siglo XXI a pensar de forma crítica o deberían los docentes implementar estrategias para potenciar el pensamiento crítico? El desarrollo de habilidades de pensamiento crítico requiere ciertos cambios dentro del sistema educativo, incluyendo un rediseño del currículum. Debido a las características distintivas de los nativos digitales, es necesario aplicar un enfoque diferente para desarrollar habilidades de pensamiento crítico. A pesar del demostrado éxito del Aprendizaje Basado en Proyectos (ABP) en Ciencias, Tecnología, Ingeniería y Matemáticas para la mejora de la competencia de los estudiantes en asignaturas STEM (Ciencias, Tecnología, Ingeniería y Matemáticas, por sus siglas en inglés), existen pocos estudios sobre su efectividad en el desarrollo de habilidades de pensamiento crítico. La ausencia de investigación adecuada dificulta la evaluación de la efectividad de la educación STEM en el fomento de habilidades de pensamiento crítico y su integración en institutos de formación profesional.

Para cubrir esta falta de literatura científica, se ha realizado una investigación extensa con dos estudios.

Un primer estudio basado en una metodología cuantitativa para determinar si la educación de Aprendizaje Basado en Proyectos (ABP) en disciplinas STEM influye en el interés de los estudiantes por las asignaturas STEM y en el desarrollo de habilidades de pensamiento crítico, para lo cual se administró el *STEM Semantics Survey* y el *Watson and Glaser's Critical Thinking* (diseño cuasiexperimental pre-test / post-test), respectivamente. Los cuestionarios se han administrado a 150 estudiantes de 1º de Bachillerato (75 en el grupo control y 75 en el grupo experimental).

El estudio 2, de naturaleza cualitativa, se basó en entrevistas a cuatro profesores y tres estudiantes de 1º de Bachillerato. Este estudio se centró en conocer si el ABP puede crear aprendizaje efectivo para estudiantes de disciplinas STEM desde la perspectiva de profesores y estudiantes.

La investigación encontró que el ABP mejora el interés de los estudiantes por asignaturas STEM y promueve el pensamiento crítico, ya que proporciona experiencias de la vida real a los estu-

diantes. Al enfrentarse al ABP, los estudiantes fueron capaces de expandir su conocimiento y satisfacer su curiosidad. Sin embargo, la investigación tiene limitaciones, como, por ejemplo, las complicaciones derivadas de la pandemia por COVID-19 y el reducido número de entrevistas. Entrevistas cara a cara y un tamaño de muestra mayor habrían dado resultados más esclarecedores.

Los hallazgos de esta investigación contribuyen a subsanar la falta de estudios sobre el pensamiento crítico en EAU. Por otro lado, los resultados de la investigación muestran los beneficios de una metodología docente como es el ABP, en este caso, aplicado a asignaturas STEM, en la mejora del interés por la mismas y del pensamiento crítico. Todo ello permite un replanteamiento de los currículos educativos integrados en asignaturas STEM.

# 1. MARCO TEÓRICO DE LA INVESTIGACIÓN

EAU tiene como objetivo fortalecer su posición mundial a través de su Estrategia de Cuarta Revolución Industrial (UAE, 2023). Asimismo, espera potenciar su contribución a la economía nacional invirtiendo en innovación y tecnología del futuro (United Arab Emirates Ministry of Industry & Advanced Technology, 2023). Además, EAU se ha propuesto convertirse en el líder mundial en adoptar tecnología punta para mejorar la sociedad, fomentar la felicidad de la ciudadanía y asegurar la sostenibilidad (UAE, 2022), así como proyectar una imagen de país sostenible propulsado por inteligencia artificial (IA) (UAE, 2023). Este objetivo se consigue priorizando varios factores, entre ellos las innovaciones relacionadas con la educación (Al Mualla, 2020), la IA (Sova Assessment, 2023) y la medicina genética.

El desarrollo de la educación innovadora en un ambiente de aprendizaje comprensivo será igualmente beneficioso para la ciencia, la nanotecnología y la IA. La medicina genómica inteligente y personalizada contribuirá al avance de la tecnología médica customizada, a la vez que fortalecerá la posición de EAU como núcleo mundial para la sanidad. Un elemento fundamental para mejorar la telemedicina y desarrollar soluciones médicas punteras, como dispositivos implantables o portables, es el uso de la robótica y la investigación nanotecnológica (UAE, 2022). La educación juega un papel relevante en la Cuarta Revolución Industrial en EAU (WAM, 2017), pues potenciará los resultados académicos y satisfará las demandas del futuro (Saif et al., 2021). Además, como parte del plan estratégico, las generaciones futuras adquirirán sofisticadas habilidades científicas y tecnológicas en el marco de un sistema de educación aplicada para prepararlas para la Cuarta Revolución Industrial, estableciendo una cantera de talento nacional sin precedentes (UAE, 2022).

## 1.1. LA CUARTA REVOLUCIÓN INDUSTRIAL EN HABILIDADES PROFESIONALES – EAU

Economías basadas en conocimiento, como la de EAU, están impulsadas por la competencia y la creatividad (UAE Vision, 2018). Por eso, se está prestando especial atención al desarrollo de los jóvenes en habilidades de áreas técnicas y profesionales. EAU ha reconocido la necesidad de enfatizar el papel que juega la educación y la Formación Técnica y Profesional (EFTP) para enfrentar los retos de un mundo propulsado por la innovación. Por tanto, para incrementar la empleabilidad de los emiratíes y cerrar la brecha competencial, EAU está priorizando la EFTP.

Para asegurar empleos para los estudiantes emiratíes, EAU ha ideado un programa de nacionalización que está siendo aplicado también en otros países del golfo (Khan & Saxena, 2022), conocido como emiratización, cuyo objetivo es introducir emiratíes en el mercado laboral público y privado (WAM, 2022), además de reducir el número de trabajadores extranjeros en EAU e incrementar la contratación de ciudadanos locales, combatiendo así el desempleo juvenil (UAE, 2021).

A través de la emiratización, el gobierno está imponiendo normas que obligan a las compañías a contratar un número concreto de ciudadanos procedentes de EAU. Por cada estudiante emiratí que obtiene un título universitario, se necesitan otros diez emiratíes con experiencia profesional para construir la economía de conocimiento del país (UAE, 2022).

## 1.2. STEM EN EL CURRÍCULUM

La integración de la enseñanza se entiende como la organización de asignaturas que no han sido previamente impartidas en un curso académico o departamento de manera conjunta, pero que se encuentran interrelacionadas o que pueden ser susceptibles de relacionarse entre sí (Joglekar et al., 1994). Para satisfacer la demanda de más estudiantes STEM, los centros educativos de enseñanza primaria y secundaria están integrando currículums y pedagogías basadas en STEM (Margot & Kettler, 2019). Sin embargo, contextualizar la ciencia, la tecnología, la ingeniería y las matemáticas en aplicaciones prácticas puede ser tan difícil como fabricar las herramientas necesarias para que una nueva generación de profesionales STEM superen las barreras globales.

En relación con el currículum, Bagiati y Evangelou (2015) observaron que los profesores siguen encontrando obstáculos. Tal y como explican estos autores, a los profesores les preocupa implementar contenidos curriculares que no son propios de sus asignaturas. Esta situación también ha sido advertida por Margot y Kettler (2019). Además, el profesorado también se encuentra inseguro por la incertidumbre en cuanto a flexibilidad curricular. La integración curricular es una característica propia de los modelos STEM (Gunawan & Shieh, 2020). Los estudios de Le et al. (2021) indicaron que a los profesores les preocupa la falta de currículums estandarizados, materiales y modelos adecuados para impartir asignaturas STEM, ya que los estudiantes reciben conocimiento fundamental dentro de campos específicos, mientras que los materiales y equipamiento se destinan a otras áreas, lo cual les impide promover el aprendizaje interdisciplinario. Los profesores también encuentran barreras para identificar conceptos STEM para el currículum y carecen de la guía necesaria para integrar STEM en el aula.

## 1.3. STEM Y FORMACIÓN DOCENTE

Se ha identificado una falta de conocimiento en temas STEM como consecuencia de una inadecuada formación (Margot, 2019). Por su parte, Pelger (2022) observó que la formación docente juega un papel crítico para facilitar la correcta implementación de currículums STEM. Al Salami et al. (2017) argumentaron que existe una insuficiente formación docente para la adaptación STEM. Como muestran los resultados de Bagiati y Evangelou (2015), los profesores son conscientes de la importancia de integrar conceptos STEM en sus prácticas docentes, pero no confían en su capacidad para aplicar estos conceptos de forma efectiva en el aula. No obstante, la formación profesional ofrece beneficios considerables para educadores que se especializan en STEM (Zhou et al., 2023). Según estos autores, se puede categorizar a las actividades de desarrollo profesional STEM como actividades basadas en ingeniería, indagación, problemas y proyectos, o como actividades integradas de STEM. Los profesores se benefician de estas actividades en términos de conocimiento y práctica, además de potenciar su comprensión sobre las disciplinas STEM. En el estudio de Gok (2022), los profesores entrevistados describieron desafíos en la integración de la educación STEM en sus prácticas docentes, sobre todo en matemáticas y ciencias de la computación.

## 1.4. LA NECESIDAD DE LA EDUCACIÓN STEM EN EAU

EAU ha reconocido la importancia de la educación STEM para preparar a sus estudiantes para los desafíos del futuro. Ha establecido objetivos para promover el aprendizaje STEM en todos los niveles educativos. La Visión de EAU para 2018 pretendía crear una economía basada en el conocimiento promovida por la innovación y la educación STEM se consideró como un componente crucial para alcanzar esta meta. Sin embargo, hay varios retos para la integración de la educación STEM en EAU, tales como la potenciación de la formación docente y el desarrollo profesional, la provisión de más oportunidades de aprendizaje práctico, y la promoción de la participación de niñas y mujeres jóvenes en campos de STEM. La solución a estos retos requerirá esfuerzos coordinados de administradores de políticas, educadores y la comunidad para asegurar que todos los estudiantes tienen acceso a una educación STEM de calidad y adquieran las habilidades y conocimientos necesarios para tener éxito en el mercado laboral del siglo XXI.

# 2. APRENDIZAJE STEM

## BASADO EN PROYECTOS Y HABILIDADES DE PENSAMIENTO CRÍTICO

La utilización de STEM en educación requiere una metodología docente diferente para hacer frente a los retos descritos anteriormente. La aplicación de la teoría constructivista puede proporcionar un marco que ayude a afrontar estos retos en la educación STEM. No obstante, la implementación de esta teoría requiere el uso de metodologías específicas y personalizadas que faciliten la integración de STEM en el aula y fomenten el desarrollo del pensamiento crítico en los estudiantes. Este apartado explora la teoría constructivista que sirve como base para esta investigación e introduce el Aprendizaje Basado en Proyectos en asignaturas STEM, así como las habilidades de pensamiento crítico.

### 2.1. LOS ORÍGENES DEL APRENDIZAJE BASADO EN PROYECTOS (ABP) Y SU RELACIÓN CON STEM

Los enfoques de aprendizaje basado en proyectos (ABP) incorporan el constructivismo, el cual está enfocado en "aprender haciendo". La Universidad McMaster en Canadá fue la primera universidad en implementar al ABP como práctica común en la educación médica (Neville & Norman, 2007). Según Capraro y Capraro (2013), el ABP es una metodología instructiva que proporciona experiencias realistas (Paredes & Vázquez, 2019), las cuales son vitales para que los estudiantes construyan ideas genuinamente científicas, tecnológicas, ingenieriles y matemáticas. Además, el ABP mejora las experiencias de aprendizaje y empodera a los estudiantes para que lleguen a ser expertos en STEM con habilidades del siglo XXI (Beals, 2019). Por consiguiente, el ABP está reconocido entre los educadores como una metodología instructiva adecuada y se ha introducido en las aulas STEM (Han, 2017).

En el ABP, a los estudiantes se les suele proponer un amplio menú de consultas, un problema específico para comprender o un asunto complejo para investigar (Sahin, 2013). Los profesores pueden alentar a los estudiantes a que identifiquen temas concretos que capten su interés o estén en línea con sus aspiraciones profesionales o pasiones personales. El ABP es una metodología instructiva que pone al estudiante en el centro del proceso de aprendizaje, utilizando una exploración activa de problemas y retos del mundo real para profundizar su comprensión sobre la materia (Ozier, 2017). Este enfoque proporciona oportunidades para vivir experiencias de aprendizaje inmersivo, así como para el desarrollo de habilidades críticas relevantes para los contextos académicos y profesionales (Buck Institute for Education, s. f.). El ABP en asignaturas STEM ha demostrado su efectividad para potenciar el conocimiento científico, tecnológico, ingenieril y matemático de los estudiantes.

Diversos estudios aseguran que el ABP es un método efectivo para impartir asignaturas STEM. Además, los estudios incluidos en esta investigación han resaltado que las habilidades de pensamiento crítico están entre las habilidades del siglo XXI que los estudiantes desarrollan cuando se integra el ABP en el currículum STEM. Según el estudio de Rochim et al. (2021), los métodos convencionales de aprendizaje constituyen el factor principal que afecta a los resultados del aprendizaje de los estudiantes. Los modelos de ABP integrados en STEM son efectivos para mejorar dichos resultados. En consecuencia, los autores argumentaron que el ABP integrado en STEM puede mejorar la capacidad de los estudiantes para lograr sus primeros resultados de aprendizaje en el colegio/instituto de manera sostenible y sinérgica. Por otra parte, Sarwi et al. (2021) abogan por la integración del ABP en la educación STEM. Es esencial que los centros STEM inclusivos sigan el enfoque de ABP (Noble et al., 2020). Según Navy y Kaya (2020), el ABP es una potente herramienta pedagógica para la integración de STEM, ya que prepara a los estudiantes para el mundo real, enseña que el fracaso no es malo y que la STEM sienta las bases del éxito futuro. Además, Rasul et al. (2016) descubrieron que la ABP en educación STEM puede potenciar las habilidades del siglo XXI de los estudiantes al proporcionar experiencias de la vida real para resolver problemas del mundo real. Los resultados del estudio de Rochim et al. (2021) mostraron de forma constante que los modelos de ABP integrados en asignaturas STEM mejoran los resultados de aprendizaje en ciencia, física y matemáticas. El ABP también ha demostrado su efectividad en la educación de la ciencia (Markula & Aksela, 2022). LaForce et al. (2017) también han documentado que el ABP tiene el potencial para aumentar las actitudes e interés de los estudiantes sobre asignaturas STEM.

## 2.2. PENSAMIENTO CRÍTICO

El proceso de pensamiento crítico implica reflexionar sobre un problema y decidir qué pensar o hacer en base a los resultados, es decir, no sólo como una decisión sobre qué debe uno pensar o creer, sino también como un procedimiento de actuación apropiado (Ennis, 2013). Por su parte, Moreno (2015) ha sugerido que las habilidades de pensamiento crítico deberían enseñarse en combinación con la instrucción matemática. En la opinión del autor, la enseñanza conceptual es un método para cultivar las habilidades de pensamiento crítico en los estudiantes. Estos últimos pueden aplicar estas habilidades a las matemáticas y otras áreas STEM o de ciencias sociales (Moser & Chen, 2016). En línea con las sugerencias de los autores, las habilidades de comprensión son cruciales para los estudiantes y serán beneficiosas para ellos a lo largo de sus carreras profesionales. Además, estos autores afirman que la capacidad para transmitir habilidades y conocimiento es más ventajosa que la mera transmisión de datos, ya que esto último puede quedar obsoleto en el futuro.

## 2.3. LA CONEXIÓN DEL PENSAMIENTO CRÍTICO CON EL ABP APLICADO EN ASIGNATURAS STEM

Varios estudios han relacionado el pensamiento crítico con el ABP aplicado en asignaturas STEM (Eja et al., 2020; Oyewo et al., 2022; Rahmawati et al., 2021). Como parte de su estudio, Eja et al. (2020) evaluaron la capacidad de los estudiantes para pensar de forma crítica en un ambiente ABP aplicado a asignaturas STEM y observaron que promueve un alto nivel de pensamiento crítico a través de su proceso de contemplación, consulta, descubrimiento, aplicación y comunicación. En la investigación de Oyewo et al. (2022), los estudiantes desarrollaron productos innovadores a través de la exploración activa de actividades de ABP sobre tratamiento de aguas, mejorando sus habilidades de pensamiento crítico. Los hallazgos de estos autores indican que las actividades de ABP potencian las habilidades de pensamiento crítico de los estudiantes y que el ABP en asignaturas STEM puede ayudar a los estudiantes a explicar conceptos de forma simple (Rahmawati et al., 2021).

# 3. FUNDAMENTOS, PROPÓSITO Y OBJETIVOS DE LA INVESTIGACIÓN

EAU juega un papel importante en la dotación de competencias a sus ciudadanos para garantizar su futuro empleo. Como respuesta a una escasez de profesionales cualificados, se ha contratado a un gran número de expatriados para cubrir estos puestos. Si este problema no se aborda con éxito, es muy posible que se incremente el desempleo juvenil en EAU y otros países de la zona. Para atajar este problema, es preciso atraer más estudiantes a la formación profesional, diseñar estudios para potenciar las competencias profesionales de los estudiantes, así como aplicar métodos de enseñanza y aprendizaje que estimulen su interés por estos estudios. Por tanto, la integración de STEM en carreras técnicas y la implementación de metodologías ABP pueden ser estrategias efectivas para lograr esta meta. Sin embargo, el ABP aplicado a asignaturas STEM puede ser relativamente nuevo en EAU.

Se han realizado pocos estudios que evalúen su efectividad para mejorar el rendimiento matemático de los estudiantes y desarrollar sus habilidades de pensamiento crítico, así como su integración en los institutos. Hoy en día, sólo hay dos centros educativos en EAU que utilizan ABP de STEM, la Escuela Modelo Al Ibdaa y la Escuela Modelo Omar Bin Al Khattab, con el objetivo de preparar a los estudiantes para su futuro (Edarabia, 2015), aunque existe un creciente consenso entre profesionales, educadores y familias en EAU sobre la idea de que la educación STEM proporciona conocimiento fundamental y que es crucial para conseguir una carrera de éxito. Además, la educación STEM está extendida en otros países árabes de la zona, en estrecha conexión con sus agendas nacionales. Parece haber un futuro prometedor para el ABP aplicado a asignaturas STEM en Medio Oriente, especialmente en EAU (John & Varghese, 2018). A pesar de esto, hay una escasez de estudios sobre su efectividad en el desarrollo de procedimientos de enseñanza ABP en asignaturas STEM para institutos de formación profesional. Por ello, nos proponemos investigar sobre la efectividad de la educación STEM en la formación de los estudiantes, concretamente en el desarrollo de habilidades de pensamiento crítico y su integración en institutos de formación profesional.

## 3.1. IMPORTANCIA DE ESTA INVESTIGACIÓN

Esta investigación gira en torno a la efectividad del ABP aplicado en asignaturas STEM en una mejora del interés de los estudiantes por este tipo de asignaturas y en el fomento de las habilidades de pensamiento crítico en estos. Los docentes pueden utilizar esta información para comprender mejor los factores que contribuyen a obtener buenos resultados y decisiones informadas por parte de sus estudiantes. Por otra parte, este estudio puede ayudar a los profesionales a identificar las debilidades y abordar las limitaciones del ABP aplicado a asignaturas STEM. Al arrojar luz sobre la efectividad del ABP en asignaturas STEM, esta investigación puede contribuir al continuo esfuerzo para mejorar la calidad educativa y garantizar que los estudiantes adquieran las destrezas y competencias necesarias para triunfar en el siglo XXI.

## 3.2. PROPÓSITO DE ESTA INVESTIGACIÓN

En primer lugar, esta investigación pretende demostrar que el ABP potencia el interés de los estudiantes por las asignaturas STEM, así como, evaluar la efectividad del ABP en la mejora de sus habilidades de pensamiento crítico. En segundo lugar, trata de conocer si el ABP puede crear aprendizaje efectivo para estudiantes de disciplinas STEM desde la perspectiva de profesores y estudiantes. Para ello, se realizaron dos estudios en esta investigación: uno cuantitativo y otro cualitativo.

## 3.3. OBJETIVOS

Los objetivos de esta investigación fueron los siguientes:

1. Determinar cómo el ABP afecta el interés de los estudiantes por las asignaturas STEM (Estudio 1).

2. Analizar el impacto de la instrucción ABP aplicado a las asignaturas STEM en el desarrollo de habilidades de pensamiento crítico de los estudiantes, considerando cambios en sus habilidades de pensamiento crítico antes y después de la intervención del ABP (Estudio 1).

3. Reconocer que el ABP puede crear aprendizaje efectivo para estudiantes en disciplinas STEM desde la perspectiva de profesores y estudiantes (Estudio 2).

## 3.4. HIPÓTESIS Y PREGUNTAS DE INVESTIGACIÓN

Para responder al primer estudio propuesto en esta tesis, se formularon las siguientes hipótesis:

1. El interés STEM de los estudiantes que reciban la intervención de ABP mostrará una diferencia estadísticamente significativa con respecto a aquellos que reciban instrucción tradicional, siendo los primeros quienes muestren mayor interés por asignaturas STEM (Estudio 1).

2. Se encontrarán diferencias estadísticamente significativas en las habilidades de pensamiento crítico entre los estudiantes que reciban instrucción ABP en STEM y aquellos que reciban instrucción convencional en STEM (Estudio 1).

Para responder al segundo estudio de esta tesis, se formuló la siguiente pregunta de investigación: ¿Cómo puede el ABP promover el aprendizaje efectivo?

# 4. METODOLOGÍA

Creswell (2009) sugiere que el primer paso en la selección de un enfoque metodológico apropiado es definir la filosofía de investigación que se quiere aplicar. Rehman y Alharthi (2016) concluyeron que esto implica un examen crítico de las propias percepciones de la realidad, identificando lo que se puede aprender de ello, y determinando cómo adquirir el conocimiento. Este marco se aplica para evaluar los componentes metodológicos del proyecto de investigación, incluyendo la elección de procedimientos de investigación y la manera en que se manipulan los datos (Kivunja & Kuyini, 2017).

## 4.1. PARADIGMA DE INVESTIGACIÓN

Entre los paradigmas existentes, esta investigación adopta una posición pragmática. Desde una perspectiva pragmática, la realidad se percibe y se renegocia continuamente contra el contexto de varias metodologías instructivas diseñadas para fomentar el pensamiento crítico en los estudiantes. El pragmatismo combina filosóficamente metodologías cualitativas y cuantitativas (Mitchell, 2018). La técnica empleada en esta investigación ha sido la encuesta, mientras que los instrumentos utilizados han sido cuestionarios y entrevistas. Los cuestionarios son un medio común para recabar datos en investigación cuantitativa y juegan un papel crucial en la obtención de información precisa e inequívoca. A pesar de esto, no logran capturar explicaciones más profundas de los participantes, por ello se realizaron también entrevistas. El objetivo era lograr una perspectiva más completa integrando datos cualitativos y cuantitativos. Hemos observado que el paradigma pragmático es el más adecuado para la comprensión del pensamiento crítico a través del contraste de hipótesis utilizando cuestionarios, y con entrevistas para completar el proceso de investigación.

## 4.2. ENFOQUE DE INVESTIGACIÓN

Creswell (2014) explicó que el enfoque de investigación dirige el estudio y guía al investigador en la formulación de un adecuado diseño de investigación, método de recopilación de datos y método de análisis, así como la presentación de la investigación, para aplicarla al área de estudio.

Los enfoques de investigación más utilizados son el cuantitativo y el cualitativo. Las diferencias entre ambos se encuentran en cómo se recopilan los datos (Polit & Beck, 2014). Los métodos de recogida de datos se seleccionan en base al tipo de datos que se van a recabar. Los métodos de investigación cuantitativa suelen emplear encuestas, datos ordinales y nominales, análisis estadísticos, y experimentos, tal como apuntaron Crookes y Davies (2004). Por su parte, Polit y Beck (2014) identificaron las entrevistas, los estudios de casos, los hallazgos y los testimonios como métodos de investigación cualitativa.

El uso de investigación cuantitativa es común en investigaciones científicas en los que se pueden cuantificar los datos (Bryman, 2012). La investigación cuantitativa se ha caracterizado por tres desarrollos históricos, principalmente el diseño, contraste y evaluación de la investigación (Kabir, 2016). Para garantizar la conformidad con el método empleado para recopilar datos estadísticos, se utiliza un método de consulta (Williams, 2007). No obstante, la consistencia de los resultados es una preocupación frecuente en la investigación cuantitativa.

En la investigación por encuestas, los métodos de investigación cuantitativa, tales como la utilización de cuestionarios, se pueden combinar con métodos de investigación cualitativa, como, por ejemplo, preguntas abiertas. Debido a su frecuente uso en la investigación y descripción del comportamiento humano, se suelen emplear encuestas en la investigación social y psicológica (Ponto, 2015). Este autor argumenta que se puede utilizar la encuesta para capturar un amplio rango de información acerca de objetivos de estudio, estrategias de reclutamiento y muestreo, métodos de recopilación de datos, y procedimientos de administración de encuestas. La investigación por encuestas emplea variables independientes y dependientes para delinear los parámetros de estudio (Christopher & Udoh, 2020). Estos investigadores afirman que el diseño de encuesta se emplea con frecuencia para describir, dilucidar y predecir la condición de ciertos fenómenos y variables, así como sus interconexiones, en un contexto de vida real y entre varias cohortes de edad, ya que la población presenta heterogeneidad. En nuestro caso, el primer estudio presentado en esta tesis sigue un método de naturaleza cuantitativa (cuasi-experimental con pretest-postest).

Por su parte, Rahman (2017) argumentó que los métodos de investigación cualitativa no dependen de medidas cuantificables (p.ej., números) para extraer conclusiones. El análisis cualitativo enfatiza realidades cotidianas tales como experiencias personales, comportamiento social, emociones y sentimientos. En comparación con la investigación cuantitativa, en la que se minimiza la inferencia humana, la investigación cualitativa implica que el investigador participe activamente en la comprensión de los participantes (Creswell, 2009; Rahman, 2017). El enfoque cualitativo pretende explicar el realismo del mundo cotidiano (Polit & Beck, 2014). Se han utilizado grupos de discusión, observaciones de los participantes, fotografías, notas de diario, y entrevistas no estructuradas como métodos de recopilación de datos (Trochim & Donnelly, 2008). Este método se basa en una muestra obtenida por conveniencia para la organización del estudio y la exploración de los participantes (Creswell, 2009), y es más flexible que la metodología cuantitativa, permitiendo el ajuste de los datos a lo largo del proceso de investigación. Sin embargo, es importante recordar que los estudios cualitativos tienen algunas desventajas, como, por ejemplo, tamaños de muestra pequeños, lo cual dificulta la generalización de los resultados de la muestra de estudio a la población general (Atieno, 2009). El segundo de los estudios presentados en esta tesis sigue una metodología de corte cualitativo.

# 5. FASE DE PLANIFICACIÓN DE ABP

La fase de planificación de ABP proporciona una discusión detallada de cada fase implicada en el diseño del programa de intervención. El desarrollo de un plan de ABP para aplicarse en asignaturas STEM comienza con un plan de proyecto. Esta fase conlleva la conceptualización del proyecto y la identificación de los profesores que participarán en el mismo. Con la ayuda del director del centro, enviamos una petición formal a los profesores para explicarles el concepto de ABP aplicado a las asignaturas STEM. Se programó la formación para la última semana de agosto de 2020, coincidiendo con la vuelta de los profesores de sus vacaciones de verano. Los profesores suelen volver a sus puestos de trabajo una semana antes que los estudiantes. El momento fue oportuno, ya que los institutos de tecnología aplicada suelen organizar sesiones de desarrollo profesional para profesores durante dicha semana. Por tanto, la formación de ABP en asignaturas STEM se convirtió en una parte integral de su programa de desarrollo profesional. Dos expertos del grupo de desarrollo curricular impartieron esta formación en el Campus Umm Al Quwain Campus. Diez maestros asistieron a la sesión: seis del departamento de ciencias (especializados en física, química y biología) y cinco del departamento de ingeniería. Se dedicó toda una semana a la formación. Cada profesor recibió un certificado al final de la formación. Tres profesores implementaron las actividades de ABP más exitosas durante el estudio, y se les dio un día libre extra como recompensa, el cual podían tomar al final de la semana previa al descanso.

## 5.1. IDEA Y VALIDACIÓN DEL PROYECTO

Este proyecto implica la construcción de un *Snail Car* y la exploración de una variedad de aplicaciones, tales como el control de velocidad del vehículo empleando un enfoque matemático (con relación, proporción, probabilidad y circunferencia de neumáticos); el cálculo de la velocidad media del coche a lo largo de una distancia y tiempo específicos como aplicación científica; la construcción de circuitos eléctricos como aplicación de ingeniería; y el empleo de programas de simulación como aplicación tecnológica.

Tras formular una idea, es necesario validarla contestando a las siguientes preguntas clave:

1. ¿Tiene este proyecto el potencial necesario para captar la atención de los estudiantes?
2. ¿Este proyecto capta la atención de los profesores?
3. ¿Este proyecto ofrece oportunidades significativas para los estudiantes?

Para responder a estas preguntas, se revisó el currículum de Ingeniería y Ciencia de 1º de Bachillerato con el fin de garantizar la inclusión de los temas abordados y empleados en la construcción del *Snail Car*. Se les pidió a los profesores participantes en este estudio que validaran el contenido de sus currículums para garantizar que sus asignaturas estaban incorporadas en el proyecto. También les preguntamos a los profesores si creían que el *Snail Car* era un proyecto STEM adecuado para llamar la atención de los estudiantes y ofrecerles oportunidades de aprendizaje significativas. Los profesores confirmaron que el *Snail Car* podía cumplir con estos objetivos. Con el *Snail Car*, los estudiantes tendrán la oportunidad de adquirir formación práctica, enfatizando el aprendizaje constructivista y fomentando una mentalidad de crecimiento.

Se partió de tres criterios de pregunta esenciales para que el diseño del *Snail Car* funcionase.

- Debe ser una pregunta que se plantea en el mundo real.
- No debe haber una respuesta fácil a esta pregunta.
- Lo ideal es que la pregunta despierte la imaginación de los estudiantes y potencie su capacidad para pensar de forma crítica.

A los estudiantes se les hicieron preguntas sobre el *Snail Car* que iban a construir para desarrollar el pensamiento crítico antes de empezar el proyecto.

- ¿Qué es un dispositivo de entrada? Explica por qué es necesario un dispositivo de entrada.
- ¿Qué es un dispositivo de salida? Explica por qué es necesario un dispositivo de salida.
- ¿Cómo podemos controlar la velocidad del coche?
- ¿Cómo podemos controlar la potencia de la corriente eléctrica en un circuito?
- ¿Qué dispositivo consume más electricidad en un coche?
- ¿Existe alguna manera de ahorrar electricidad? Razona tu respuesta.
- ¿Cómo se puede maximizar la electricidad que se transmite a una carga?

- Explica cómo se carga un condensador (crecimiento exponencial).

Se consideró necesario realizar una sesión de *brainstorm* colaborativo con los profesores de la escuela antes de empezar el estudio, ya que esto podía potenciar el éxito del estudio y del proyecto seleccionado. Para facilitar el intercambio de mejores prácticas entre los profesores y obtener *feedback*, se discutió el siguiente tema: hasta qué grado este proyecto cumple los principios de ABP de Adria Steinberg (Steinberg, 1997):

- ¿Qué se puede hacer para mejorar la conexión del proyecto con la comunidad?
- ¿Existe alguna posibilidad de que se presente el resultado final de forma diferente?
- ¿Hay alguna organización que esté interesada (por ejemplo, universidades u otros centros educativos)?

## 5.2. OBJETIVOS DE ABP APLICADO A ASIGNATURAS STEM PARA LOS PROFESORES INCLUIDOS EN ESTA INVESTIGACIÓN

Para garantizar el desarrollo de habilidades de pensamiento crítico entre los estudiantes, es esencial atraer su atención hacia el proceso de construcción del *Snail Car*. Por tanto, es fundamental que los profesores participantes tuvieran objetivos específicos relacionados con STEM.

- Enseñar conceptos básicos de ratios.
- Enseñar proporciones y ecuaciones con variables en ambos lados.
- Enseñar a los estudiantes a encontrar la probabilidad de eventos simples.
- Proporcionar a los estudiantes instrucciones sobre cómo determinar la velocidad media de un objeto en base a la distancia que ha recorrido en un periodo de tiempo concreto.
- Enseñar a los estudiantes a calcular la circunferencia de un círculo (el neumático de un coche).
- Explicar que la circunferencia de un neumático corresponde a la distancia recorrida por un coche, ya que la circunferencia del neumático se correlaciona con una revolución de la rueda.
- Comprender los componentes del circuito eléctrico seleccionados.

## 5.3. EXPECTATIVAS DE LOS ESTUDIANTES SOBRE LOS INDICADORES DE RENDIMIENTO CLAVES DEL *SNAIL CAR*

Los indicadores de rendimiento claves (IRCs) de los resultados de aprendizaje fueron los siguientes:

- Calcular ratios. Aquí, los estudiantes debían considerar factores como el tamaño y peso del *Snail Car* y la velocidad deseada.
- Solucionar proporciones y ecuaciones con variables en ambos lados. Para esto, los estudiantes debían usar manipulaciones algebraicas y prestar atención a los detalles. Fue esencial que los estudiantes entendieran la ecuación específica con la que trabajaban y aplicaran las técnicas apropiadas.
- Encontrar la probabilidad de un evento simple. A los estudiantes se les pidió que calcularan la probabilidad de que el *Snail Car* recorriese una distancia determinada en un periodo de tiempo concreto.
- Hallar la velocidad media del coche, considerando la distancia total recorrida por el coche en un periodo de tiempo concreto. A los estudiantes se les pidió que calcularan el tiempo que tardaría el coche en recorrer la distancia y el tiempo que en realidad tardó en recorrer esa distancia.
- Hallar la circunferencia de un círculo (el neumático del coche). Los estudiantes tuvieron que utilizar medidas.
- Comprender cómo la circunferencia del neumático de un coche se puede utilizar para estimar la distancia recorrida por el vehículo en base a las revoluciones de la rueda. A los estudiantes se les pidió que estimaran la distancia recorrida por el vehículo.

## 5.4. HABILIDADES DESARROLLADAS POR LOS ESTUDIANTES PARTICIPANTES EN LA INVESTIGACIÓN

Los estudiantes participaron en un proceso de prototipado práctico utilizando materiales asequibles como Legos para el proyecto de *Snail Car*. Los estudiantes fueron responsables de ensamblar estos componentes para que completar el proyecto correctamente. Se les alentó a pensar de forma creativa a través del ABP y el desarrollo de un prototipo físico, el cual les proporcionó la oportunidad de probar sus ideas, identificar problemas potenciales, realizar estudios, y hacer las mejoras oportunas para validar su comprensión conceptual. El prototipado, estudio y refinado iterativo del diseño final fueron partes integrales del proceso de ABP aplicado en asignaturas STEM. Los estudiantes que se involucraron en estas actividades desarrollaron sus habilidades de solución de problemas, pensamiento crítico, creatividad y colaboración.

# 6. ESTUDIO 1.
## EFECTOS DEL ABP EN EL INTERÉS DE LOS ESTUDIANTES POR ASIGNATURAS STEM Y EL DESARROLLO DEL PENSAMIENTO CRÍTICO

El primer estudio de esta tesis doctoral estuvo enfocado en el análisis de los efectos de la aplicación del ABP en el interés de los estudiantes por asignaturas STEM, así como en el desarrollo del pensamiento crítico. En este estudio, se aplicó sendas adaptaciones de la Encuesta de Semántica STEM y el cuestionario sobre habilidades de pensamiento crítico de Watson-Glaser. La implementación del programa de intervención (ABP) en un grupo experimental permitió la realización de una investigación cuasi-experimental y aprender sobre estos resultados.

### 6.1. OBJETIVOS E HIPÓTESIS

El estudio tiene dos objetivos:

1. Determinar cómo al ABP afecta al interés de los estudiantes por asignaturas STEM.

2. Examinar el impacto de la instrucción ABP en asignaturas STEM sobre el desarrollo de habilidades de pensamiento crítico en los estudiantes, considerando cambios en sus habilidades de pensamiento crítico antes y después de la intervención con el ABP.

La hipótesis general de este estudio establece que aquellos estudiantes que reciban la intervención (ABP en asignaturas STEM) mostrarán diferencias estadísticamente significativas con respecto a aquellos que reciban la instrucción tradicional, siendo los primeros quienes muestren mayor interés por las asignaturas STEM, así como un mejor rendimiento en habilidades de pensamiento crítico. Para responder a este estudio propuesto en esta tesis, se formularon las siguientes hipótesis:

H1. El interés STEM de los estudiantes que reciban la intervención ABP será significativamente diferente de aquellos que reciban la instrucción tradicional, siendo los primeros quienes muestren un interés significativamente mayor por asignaturas STEM.

H2. Se encontrarán diferencias estadísticamente significativas en las habilidades de pensamiento crítico, siendo estas mayores en aquellos estudiantes que reciban la intervención de ABP en asignaturas STEM en comparación con los que reciban la instrucción tradicional en STEM.

## 6.2. POBLACIÓN Y MUESTRA

La población objetivo de esta investigación incluye estudiantes y profesores de un instituto de formación profesional seleccionado. La capacidad para generalizar los resultados de este estudio a todos los estudiantes de instituto de nivel de 1º de Bachillerato está limitada por la escasa disponibilidad de datos. La disponibilidad actual de datos integrales de estudiantes de nivel de 1º de Bachillerato matriculados en asignaturas STEM en todo el espectro educativo en EAU es limitada, lo cual dificulta la capacidad para reforzar los hallazgos de la investigación y hacer generalizaciones más amplias.

Se empleó el muestreo intencional en este estudio, el cual incluye estudiantes de nivel de 1º de Bachillerato matriculados en un instituto de formación profesional en Umm Al Quwain, uno de los siete emiratos de EAU. Todos los chicos de este instituto, con una edad de 15-16 años, fueron incluidos en el estudio. Estaban matriculados en signaturas STEM que les permitirían más adelante optar por carreras de ingeniería o ciencia de computación en la universidad. Los participantes fueron uniformemente distribuidos en dos grupos (control y experimental), con 75 estudiantes en cada grupo. La instrucción STEM se impartió al grupo control utilizando métodos docentes tradicionales. El ABP se empleó para enseñar STEM al grupo experimental.

## 6.3. INSTRUMENTOS Y VARIABLES

Esta sección está dividida en dos subsecciones, una para cada objetivo. Se han utilizado dos instrumentos para el Estudio 1: Encuesta de Semántica STEM y el Test de Pensamiento Crítico de Watson y Glaser. El proceso de validación y fiabilidad queda reflejado en la tesis.

### 6.3.1. **Instrumento 1: Encuesta de Semántica STEM**

Para determinar cómo el ABP afecta el interés de los estudiantes por asignaturas STEM (objetivo 1), se ha empleado la Encuesta de Semántica STEM, la cual evalúa los intereses de los estudiantes por la ciencia, la tecnología, la ingeniería y las matemáticas, así como la probabilidad de que opten por carreras en estas áreas (Stelar, s. f.).

La Encuesta de Semántica STEM contiene 37 preguntas con escala tipo Likert. Varios estudios han utilizado este instrumento con éxito en muestras de estudiantes de institutos (Çevik, 2018; Kier et al., 2013; Zhang et al., 2022).

Se ha modificado el cuestionario original en algunos aspectos específicos, ya que la lengua materna de los estudiantes era el árabe y el inglés era su segundo idioma. Se ha reconocido que la estructuración de estas preguntas en un formato consistente con sus habituales prácticas de evaluación puede facilitar un proceso evaluativo más cómodo y efectivo. Además de medir el interés por asignaturas STEM y habilidades del siglo XXI, este enfoque también considera su dominio del lenguaje, dando lugar a una evaluación más equitativa.

### 6.3.2. **Instrumento 2: Test de Pensamiento Crítico de Watson y Glaser**

El test de pensamiento crítico de Watson y Glaser es una herramienta tipo test en línea con las definiciones de Bernard et al. (2008), quien propuso que el pensamiento crítico implica "procesos descriptivos, inferenciales y de verificación". Estos procesos son análogos a los indicadores de pensamiento crítico como la interpretación, la explicación, el análisis, y la evaluación, como identificó Hapsari (2016). Por su parte, Gadzella et al. (1996) apuntaron que el test de Watson y Glaser evalúa la habilidad del candidato para resolver problemas y proporcionar explicaciones para situaciones de la vida real, los cuales son aspectos claves del pensamiento crítico. Se decidió utilizar el test de Watson y Glaser en lugar del Test de Pensamiento Crítico de California (CCTST) (Insight Assessment, 2023), ya que es el instrumento de medida de pensamiento crítico más antiguo, más utilizado y más estudiado (Possin, 2014). Por otra parte, la investigación sobre el pensamiento crítico y STEM ha demostrado la eficacia de este instrumento (Dewanti et al., 2021; Yaki, 2022).

Para garantizar la fiabilidad del test de pensamiento crítico de Watson y Glaser, se emplearon los siguientes métodos:

- Comparar nuestros resultados con los de estudios previos que han investigado constructos similares (Mutakinati et al., 2018; Sayekti & Suparman, 2020). En su estudio, Mutakinati et al. (2018) examinaron el impacto de la educación STEM implementada por ABP en las habilidades de pensamiento crítico de los estudiantes. Estos autores emplearon seis elementos del pensamiento crítico con una noción similar a los seis niveles de pensamiento crítico utilizados por Elder y Paul (2010). Los hallazgos de Mutakinati et al. (2018) revelaron que las habilidades de pensamiento crítico de los estudiantes incrementaron con el ABP. El estudio detectó que el 41.6% de los ciento sesenta participantes eran pensadores avanzados, y el 30.6% eran pensadores practicantes. En esta investigación, el ABP también se ha utilizado para enseñar STEM, lo cual mejora las habilidades pensamiento crítico de los estudiantes, tal como han demostrado Sayekti y Suparman (2020).

- Garantizar que a los participantes se les hacen las mismas preguntas.

## 6.4. VARIABLES

La dirección y el resultado de las hipótesis están condicionadas por variables independientes y dependientes. Empleando la hipótesis como guía, se puede estimar cómo la variable independiente afectará la variable dependiente (Allen, 2017).

En este sentido, la variable independiente de esta investigación es el ABP como tratamiento de intervención.

Por su parte, las variables dependientes de este estudio se describen a continuación.

- Interés por asignaturas STEM de los participantes.
- Pensamiento crítico, medido a través de cinco habilidades:  interferencia, reconocimiento de suposiciones, deducción, interpretación y evaluación de argumentos.

## 6.5. ANÁLISIS DE DATOS

Para la Encuesta de Semántica STEM, se aplicaron los siguientes estadísticos con el software SPSS V26:

- Estadísticos descriptivos (Knezek et al., 2011).
- Índice de importancia relativa (IIR). El IRR se utiliza para examinar las respuestas de cuestionarios estructurados con medidas ordinales de actitud. En base a las respuestas del cuestionario, se puede cuantificar la significancia relativa de varios factores o variables. Al asignar cargas a cada nivel de la escala ordinal, el IIR ayuda a determinar la significancia relativa de varias actitudes y opiniones expresadas por los encuestados.

## 6.6. RESULTADOS DE LA ENCUESTA DE SEMÁNTICA STEM

En esta sección se analizan los resultados de la adaptación del Cuestionario de Semántica STEM (Education Development Center, 2022). El objetivo del Cuestionario de Semántica STEM fue determinar si los estudiantes estaban interesados en asignaturas STEM. No se realizaron pre-post-test para este instrumento, ya que la evidencia empírica de estudios previos con constructos similares como los de Pérez (2019), Tyler-Wood et al. (2010) y Zhang et al. (2022) muestra que éstos no emplearon pre-post-test en su Encuesta de Semántica STEM. Esta decisión es consistente con los hallazgos de los estudios mencionados anteriormente.

Según las pruebas de Kolmogorov-Smirnov y Shapiro-Wilk, no se identificó evidencia estadística para la distribución natural del cuestionario y sus cuatro temáticas relacionadas, lo cual implica que se deberían utilizar pruebas informativas para evaluar las respuestas de los estudiantes. Para ambos grupos (experimental y control), se han analizado respuestas en base a las escalas de medida estadística. Se empleó la puntuación media y la desviación estándar como medidas de tendencia central en estadísticos descriptivos. Este instrumento es particularmente útil para categorizar prioridades basadas en escalas tipo Likert, lo cual permite identificar tendencias prevalentes. Esta técnica es apropiada para identificar los factores más influyentes en un grupo de participantes. Los resultados tanto del grupo experimental como del grupo control se muestran en la tabla 0.

**Tabla 0.** *Estadísticos descriptivos del cuestionario de Semántica STEM*

| SECTION | GROUPS | MEAN | STD. DEV. | RII | IMPORTANCE LEVEL | MEAN DIFFERENCE |
|---|---|---|---|---|---|---|
| ***Mathematics*** | Experimental | 4.1033 | 0.558 | 0.821 | High | 0.7866 |
| | Control | 3.3167 | 0.499 | 0.663 | Medium–High | |
| ***Science*** | Experimental | 4.0163 | 0.654 | 0.803 | High | 0.6356 |
| | Control | 3.3807 | 0.474 | 0.676 | Medium–High | |
| ***Engineering and Technology*** | Experimental | 4.0889 | 0.726 | 0.818 | High | 0.9452 |
| | Control | 3.1437 | 0.523 | 0.629 | Medium–High | |
| ***21st Century Skills*** | Experimental | 4.0945 | 0.521 | 0.819 | High | 0.8206 |
| | Control | 3.2739 | 0.515 | 0.655 | Medium–High | |
| ***Summary of all the questions*** | Experimental | 4.0758 | 0.545 | 0.815 | High | 0.7970 |
| | Control | 3.2788 | 0.406 | 0.656 | Medium–High | |

Los hallazgos específicos de cada área temática STEM se encuentran recogidos en la tesis y a continuación se ofrece un resumen:

- El ABP produjo un incremento de la nota media en matemáticas.
- Las notas en ciencia mejoraron significativamente; parece ser que el ABP potenció adecuadamente la comprensión de los estudiantes acerca de la relevancia de la ciencia.
- La estrategia de ABP incrementó el interés de los estudiantes por la ingeniería y la tecnología.
- El modelo de ABP mejoró en los estudiantes la adquisición de habilidades del siglo XXI.

## 6.7. RESULTADOS DEL TEST DE PENSAMIENTO CRÍTICO DE WATSON Y GLASER

El Test de Pensamiento Crítico de Watson y Glaser es una prueba que mide la habilidad de un individuo para evaluar, interpretar, racionalizar y generar inferencias lógicas. Ha sido revisado y mejorado en múltiples ocasiones (Pearson, 2020; Sternod & French, 2016) y especificado para estudiantes de institutos (Aiyub et al., 2021; Orhan & Çeviker Ay, 2022). En esta sección se presentan los resultados del Test de Pensamiento Crítico de Watson y Glaser, incluyendo los resultados del pre-test y del post-test.

### 6.7.1. Resultados pre-test (grupo experimental y grupo control)

Es fundamental realizar una evaluación del pensamiento crítico antes de implementar el ABP in los dos grupos (experimental y control). Al proporcionar percepciones factibles sobre la eficacia del ABP, esta evaluación facilita la toma de decisiones informadas sobre estrategias para mejorar habilidades de pensamiento crítico.

Los participantes fueron examinados en las cinco dimensiones del pensamiento crítico: interferencia, reconocimiento de suposiciones, deducción, interpretación y evaluación de argumentos.

El pre-test del cuestionario de pensamiento crítico incluyó preguntas teóricas y prácticas. Con las preguntas teóricas, se pretendió estimular el pensamiento crítico y la exploración intelectual en los estudiantes a través del examen de los principios, suposiciones e implicaciones de un tema concreto.

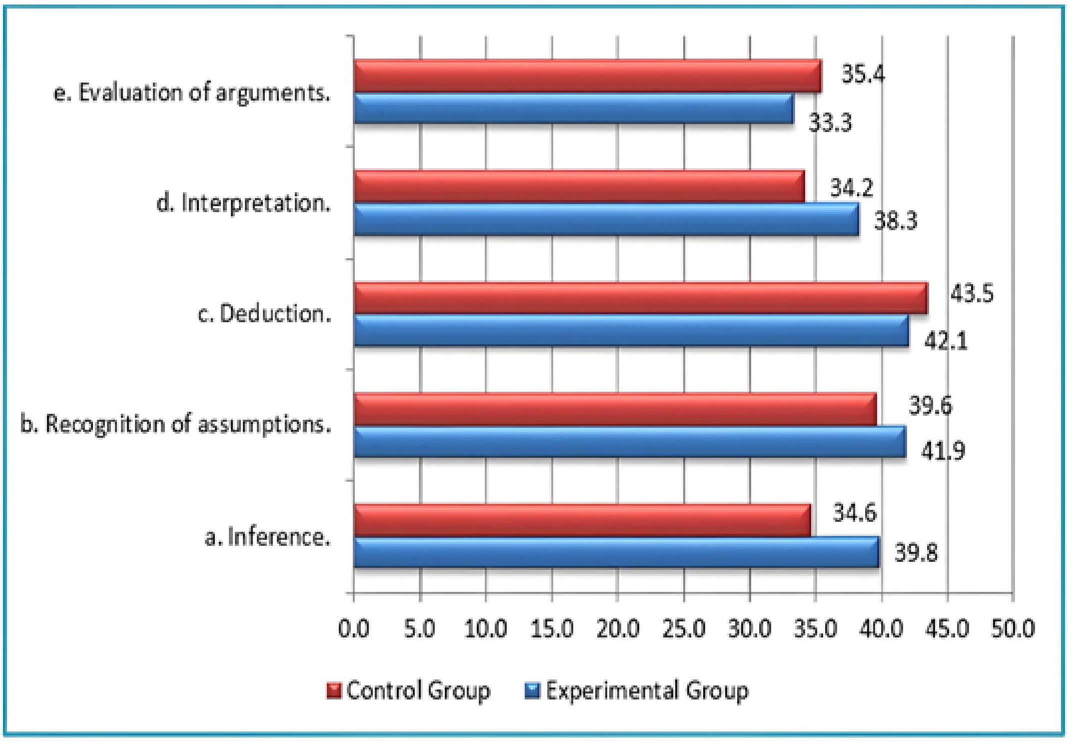
Tanto para el grupo experimental como para el grupo control, se utilizaron varias técnicas numéricas y diagramáticas para evaluar la distribución normal de las puntuaciones del test de habilidades de pensamiento crítico. Por ejemplo, la prueba de Kolmogorov-Smirnov para analizar los datos numéricos y la prueba de Shapiro-Wilk para comparar las respuestas correctas dentro de una desviación estándar entre los participantes. La prueba de inferencia estadística de Levene se empleó para determinar si los grupos experimental y control tenían habilidades de pensamiento crítico idénticas. Los test de Mann-Whitney y Wilcoxon se aplicaron para comparar las tendencias en una misma variable entre dos grupos independientes. Con estas pruebas, hemos analizado si se puede comparar el nivel promedio de las puntuaciones de habilidades de pensamiento crítico en ambos grupos, si alguna diferencia se debe al azar, o si las variaciones significativas entre los resultados de los dos grupos son sustanciales y avaladas por la evidencia estadística. Se ha determinado que la prueba de Mann-Whitney no tiene referencia estadística si el valor de la referencia estadística (Z) para las cinco habilidades de pensamiento crítico (interferencia, reconocimiento de suposiciones, deducción, interpretación, y evaluación de argumentos) es mayor que 0.05 y ($p > 0.05$), lo cual indica que la suposición del cero ha sido aceptada, y que ambos grupos recibieron las mismas notas. Los resultados de la prueba pretest y postest al grupo experimental y control se muestran en la tabla 1 y la figura 1. Su comentario más detallado aparece en la tesis.

**Tabla 1.** *Comparación del grupo control y experimental (Mann-Whitney-Wilcoxon test)*

| SKILLS | GROUPS | MEAN RANK | MANN-WHITNEY U | Z | ASYMP. SIG. |
|---|---|---|---|---|---|
| a. Inference | Experimental group | 81.83 | 2338 | -1.793 | 0.073 |
| | Control group | 69.17 | | | |
| b. Recognition of assumptions | Experimental group | 78.82 | 2563.5 | -0.941 | 0.347 |
| | Control group | 72.18 | | | |
| c. Deduction | Experimental group | 73.60 | 2670 | -0.538 | 0.590 |
| | Control group | 77.40 | | | |
| d. Interpretation | Experimental group | 77.43 | 2668 | -0.546 | 0.585 |
| | Control group | 73.57 | | | |
| e. Evaluation of arguments | Experimental group | 72.63 | 2597 | -0.817 | 0.414 |
| | Control group | 78.37 | | | |

**Fuente:** *elaboración propia*

**Figura 1.** *Comparación de las destrezas de pensamiento crítico entre el grupo experimental y el grupo control*




**Fuente:** *elaboración propia*

### 6.7.2. Resultados post-test de la adaptación del instrumento de pensamiento crítico de Watson y Glaser (grupo experimental y grupo control)

Empleando el post-test, se comparó al grupo experimental con el grupo control para determinar si los resultados del test de pensamiento crítico era diferentes después de que el grupo experimental recibiera la instrucción de ABP en asignaturas STEM, mientras que el grupo control recibió la instrucción tradicional STEM. Después de la intervención de ABP, la Tabla 2 muestra el número de respuestas correctas de los estudiantes en los grupos experimental y control, así como su rendimiento en las pruebas teóricas y prácticas de habilidades de pensamiento crítico. Como parte de las preguntas teóricas, se pusieron a prueba los principios, suposiciones e implicaciones de un tema concreto para estimular el pensamiento crítico y la exploración intelectual en los estudiantes. Al igual que en las preguntas prácticas, las preguntas teóricas no requerían el uso de calculadora.

**Tabla 2.** *Resultados de las respuestas del post-test (grupo experimental y grupo control) de pensamiento crítico*

| PREGUNTAS | | GRUPO EXPERIMENTAL | | GRUPO CONTROL | |
|---|---|---|---|---|---|
| | | Frecuencia | % | Frecuencia | % |
| **Teoría** | | | | | |
| | Pregunta (1) | 30 | 40 | 43 | 57.3 |
| | Pregunta (2) | 51 | 68 | 49 | 65.3 |
| | Pregunta (3) | 41 | 54.7 | 40 | 53.3 |
| | Pregunta (4) | 47 | 62.7 | 47 | 62.7 |
| | Pregunta (5) | 47 | 62.7 | 25 | 33.3 |
| | Pregunta (6) | 50 | 66.7 | 14 | 18.7 |
| | Pregunta (7) | 43 | 57.3 | 43 | 57.3 |
| | Pregunta (8) | 42 | 56 | 46 | 61.3 |
| | Pregunta (9) | 46 | 61.3 | 27 | 36 |
| | Pregunta (10) | 47 | 62.7 | 17 | 22.7 |
| | Pregunta (11) | 35 | 46.7 | 30 | 40 |
| | Pregunta (12) | 47 | 62.7 | 18 | 24 |
| **Practica** | | | | | |
| | Pregunta (1) | 52 | 69.3 | 51 | 68 |
| | Pregunta (2) | 49 | 65.3 | 53 | 70.7 |
| | Pregunta (3) | 43 | 57.3 | 14 | 18.7 |
| | Pregunta (4) | 45 | 60 | 51 | 68 |
| | Pregunta (5) | 23 | 30.7 | 20 | 26.7 |
| | Pregunta (6) | 16 | 21.3 | 23 | 30.7 |

| PREGUNTAS | GRUPO EXPERIMENTAL | | GRUPO CONTROL | |
|---|---|---|---|---|
| | Frecuencia | % | Frecuencia | % |
| Pregunta (7) | 53 | 70.7 | 23 | 30.7 |
| Pregunta (8) | 24 | 32 | 23 | 30.7 |
| Pregunta (9) | 54 | 72 | 23 | 30.7 |
| Pregunta (10) | 54 | 72 | 17 | 22.7 |
| Pregunta (11) | 38 | 50.7 | 41 | 54.7 |
| Pregunta (12) | 42 | 56 | 20 | 26.7 |
| Pregunta (13) | 43 | 57.3 | 48 | 64 |

**Fuente:** *elaboración propia.*

En la tabla 3 se observan las diferencias entre los resultados del pretest y del postest en las cinco destrezas de pensamiento crítico.

**Tabla 3.** *Comparación entre los resultados del pretest y del postest en las cinco destrezas de pensamiento crítico.*

| SKILLS | GROUPS | | PRE-TEST | | POST-TEST | | MEAN DIFFERENCE IN POST-TEST |
|---|---|---|---|---|---|---|---|
| | | Obs. | Mean | Std. Dev. | Mean | Std. Dev. | |
| Inference | Experimental | 75 | 39.8431 | 22.547 | 60.3137 | 26.661 | 20.471 |
| | Control | 75 | 34.5882 | 21.688 | 40.5490 | 19.571 | 5.9608 |
| Recognition of assumptions | Experimental | 75 | 41.8824 | 20.536 | 58.1961 | 22.896 | 16.314 |
| | Control | 75 | 39.6078 | 18.934 | 42.5882 | 17.801 | 2.9804 |
| Deduction | Experimental | 75 | 42.1176 | 21.451 | 57.8039 | 23.911 | 15.686 |
| | Control | 75 | 43.5294 | 20.718 | 45.4118 | 19.379 | 1.8824 |
| Interpretation | Experimental | 75 | 38.2963 | 20.147 | 54.0741 | 23.381 | 15.778 |
| | Control | 75 | 34.1852 | 19.989 | 42.0741 | 19.227 | 7.8889 |
| Evaluation of arguments | Experimental | 75 | 33.3333 | 22.636 | 53.1111 | 26.978 | 19.778 |
| | Control | 75 | 35.4444 | 21.228 | 38.5556 | 20.494 | 3.1112 |

En la tesis doctoral se puede observar un análisis más detallado y en profundidad de los resultados obtenidos.

## 6.8. DISCUSIÓN Y CONCLUSIÓN DEL CUESTIONARIO DE SEMÁNTICA STEM

Para investigar el impacto del ABP en el interés de los estudiantes por STEM, se empleó un IIR, el cual tiene un valor significativo, puesto que ofrece información sobre los factores dentro del campo de STEM que mayor influencia ejercen sobre el interés de los estudiantes por estas disciplinas. Las preferencias de los estudiantes en asignaturas STEM podrían ser mejor comprendidas con el uso del IIR.

Se ha identificado que tanto los métodos ABP y la instrucción tradicional tienen un impacto significativo en el interés de los estudiantes por disciplinas STEM. Una de las principales conclusiones derivadas de la encuesta es que el ABP parece ejercer un impacto notable y favorable en la preferencia del grupo experimental por asignaturas STEM. Por el contrario, el grupo control, que estuvo expuesto al método tradicional, mostró un reducido grado de interés por las carreras en estos campos.

Los resultado descritos sugieren la conveniencia de emplear enfoques pedagógicos como el ABP para cultivar el interés de los estudiantes por las áreas STEM. Si se capta la atención de los estudiantes a través del ABP, podrán alcanzar una comprensión más profunda de las asignaturas STEM, así como establecer conexiones entre estos conceptos y su aplicación práctica en situaciones de la vida real, incrementando así su interés e inclinación por asignaturas STEM.

## 6.9. DISCUSIÓN Y CONCLUSIÓN DEL TEST DE PENSAMIENTO CRÍTICO DE WATSON Y GLASER

Los resultados del Test de Pensamiento Crítico de Watson y Glaser han proporcionado valiosas percepciones sobre el desarrollo de habilidades de pensamiento crítico en el contexto de este estudio. Los resultados del estudio, que han sido bastante iluminadores, han revelado mejoras sustanciales entre los participantes del grupo experimental. Al demostrar este progreso significativo, fueron capaces de alcanzar la fase inicial de habilidad de pensamiento crítico. Sin embargo, el grupo control mostró rasgos y comportamientos más cercanos a los de un pensador limitado, enfatizando el papel crucial que juega el ABP.

Al revisar los aspectos específicos, se hizo evidente que la intervención de ABP tuvo un impacto significativo en diferentes aspectos del pensamiento crítico. Hubo mejoras significativas en habilidades de pensamiento crítico entre los participantes en el grupo experimental. En concreto, estas mejoras se hicieron evidentes en las áreas de detección de interferencia, reconocimiento de suposiciones, interpretación de información compleja, deducción lógica, y análisis evaluativo de argumentos. El enfoque de ABP ha proporcionado evidencias convincentes de su efectividad para fomentar el desarrollo del pensamiento crítico en cada uno de estos dominios.

En comparativa, el grupo control, cuyos participantes no se beneficiaron de la intervención de ABP, no mostraron esa mejora significativa en habilidades de pensamiento crítico. Considerando la diferencia entre los dos grupos, el ABP parece ser una técnica efectiva para potenciar las habilidades de pensamiento crítico con su incorporación en las estrategias educativas.

Este estudio demuestra que el ABP puede ser una estrategia eficaz para incrementar las habilidades de pensamiento crítico. Claramente, como evidencian los resultados, al ABP tiene la capacidad de elevar a las personas en el área de pensamiento crítico desde un estatus de pensador limitado a uno de pensador iniciado. Los resultados del Test de Pensamiento Crítico de Watson y Glaser sugieren que el ABP en educación también puede ser una herramienta efectiva para cultivar pensadores críticos más ingeniosos, perceptivos y competentes.

# 7. ESTUDIO 2:
## EFECTOS DEL ABP EN EL APRENDIZAJE PARA ESTUDIANTES DE DISCIPLINAS STEM DESDE LA PERSPECTIVA DE PROFESORES Y ESTUDIANTES

En el Estudio 2 se realizó un análisis exhaustivo de los temas, patrones y descubrimientos claves que surgieron del proceso de estudio.

### 7.1. OBJETIVO Y PREGUNTA DE INVESTIGACIÓN

El objetivo de este segundo estudio fue el siguiente: reconocer que el ABP puede crear aprendizaje efectivo para estudiantes de disciplinas STEM desde la perspectiva de profesores y estudiantes. Para este estudio, hemos intentado responder la siguiente pregunta de investigación: *"¿Cómo puede un ABP promover el aprendizaje efectivo"?*

### 7.2. PARTICIPANTES

Se empleó el muestreo intencional para realizar las entrevistas, un enfoque bien establecido en la investigación cualitativa (Given, 2008; Palinkas et al., 2015). Inicialmente reclutamos a seis profesores varones de STEM y diez estudiantes de nivel de 1º de Bachillerato, aunque la muestra final se redujo a cuatro profesores. Sólo se pudo entrevistar a cuatro profesores y tres estudiantes debido a las restricciones por COVID-19. A pesar del tamaño de muestra relativamente pequeño, confiamos en que las percepciones derivadas de nuestras entrevistas contribuirán a la literatura académica existente de forma sustancial y significativa. De hecho, se suelen emplear tamaños de muestra reducidos en investigación cualitativa y, en ocasiones, incluso un solo participante puede ser suficiente (Boddy, 2017).

## 7.3. INSTRUMENTOS

Se han llevado a cabo entrevistas estructuradas con los estudiantes y los profesores para valorar la efectividad del uso del ABP en asignaturas STEM en el desarrollo de habilidades de pensamiento crítico en un instituto de formación profesional en tecnología aplicada de EAU. En el proceso de diseño de las preguntas se consideró que debía ser imperativo que éstas generaran percepciones acerca de las perspectivas de los participantes sobre al ABP y su impacto en el pensamiento crítico.

De igual forma, se cuidó que las preguntas estuvieran formuladas de forma que permitieran, tanto a los estudiantes como a los profesores, establecer conexiones y extraer significado de sus percepciones. Por tanto, las preguntas debían proporcionarnos un *feedback* sobre las percepciones acerca del ABP y cómo éste potenció el pensamiento crítico, así como recomendaciones para métodos docentes curriculares y estructurales que facilitaran el desarrollo de habilidades de pensamiento crítico.

### 7.3.1. **Preguntas de entrevista para los estudiantes**

A los estudiantes se les hicieron las siguientes preguntas:

a) Identifica los materiales que se utilizarán para construir el *Snail Car*.
b) ¿Para qué sirve un *Snail Car* en el mundo real?
c) ¿Qué piensas sobre la construcción de un *Snail Car*?
d) ¿Cómo diseñarías un *Snail Car* si tuvieras en mente un diseño diferente al que se describe en las instrucciones?

7.3.2. Preguntas de entrevista para los profesores

A los profesores se les hicieron las siguientes preguntas:

a) ¿Has encontrado una utilidad para el *Snail Car* en el mundo real?
b) ¿Cómo te has sentido acerca del experimento de ABP de STEM?
c) ¿Ha tenido éxito el *Snail Car*?
d) ¿Qué has aprendido durante el experimento de ABP de STEM?
e) ¿Consideras que la intervención de STEM tuvo éxito?
f) ¿Qué factores contribuyeron al éxito de la intervención?
g) ¿Has notado diferencias entre los estudiantes del grupo experimental y los del grupo control?
h) ¿Podrías identificar algún reto, y cómo los estudiantes se adaptaron a ese reto?
i) ¿Has observado que los estudiantes hayan desarrollado habilidades de pensamiento crítico durante la intervención?
j) En tu opinión, ¿es efectivo el ABP en un currículum de STEM?

k) En tu opinión, ¿ha tenido la intervención un enfoque claro; un contexto de vida real que diera libertad a los estudiantes para pensar por ellos mismos; aspectos prácticos e interactivos; y un buen equilibrio entre todas las asignaturas STEM?

l) ¿Ha contribuido la intervención a comprender cómo piensan los estudiantes, mejorando así la enseñanza y el aprendizaje, y existe alguna evidencia de la efectividad de la intervención?

## 7.4. ANÁLISIS DE DATOS

Se siguieron tres fases para el análisis de datos: 1) Lectura de la información obtenida; 2) Codificación de los datos; y 3) Interpretación de los datos. Los datos cualitativos en este estudio fueron analizados con MAZQDA, el cual permite analizar un amplio rango de tipos de datos, incluyendo video, audio, página web, tweets, grupo de discusión, y encuesta (MAXQDA, 2022). Una exhaustiva revisión de casos individuales es el primer paso en el proceso de análisis de datos de MAXQDA. Este paradigma analítico se refiere a la categorización de partes de texto como categorías temáticas. En consecuencia, las entrevistas transcritas se utilizaron para clarificar temas significativos en base a las transcripciones. Durante la fase de codificación, se comparan segmentos de texto pertenecientes a la misma categoría como preparación para el posterior análisis de datos. El análisis comparativo se aplicó para examinar temas en este estudio, empleando comparaciones de contraste para revelar características comunes entre los participantes, propiedades únicas de casos específicos, y sus relaciones. Como apuntó Kuckartz (2014), los enfoques de codificación y recuperación requieren una cantidad considerable de tiempo y esfuerzo por parte de los investigadores, a pesar de su aparente simplicidad. Con el uso de códigos MAXQDA, hemos identificado múltiples temas. Algunas respuestas fueron transcritas textualmente.

### 7.4.1. Análisis de los datos obtenidos en las entrevistas con los estudiantes

Los datos de las entrevistas con los estudiantes proporcionaron percepciones sobre cómo el ABP con la construcción de un *Snail Car* y su utilidad en el mundo real han cambiado su perspectiva acerca del ABP. En primer lugar, los datos fueron codificados; la Tabla 46 muestra un resumen de los temas identificados durante el proceso de codificación. Estos temas incluyen trabajo en equipo, pensamiento crítico, solución de problemas, y ABP. En dicha tabla, hay dos columnas que contienen información obtenida de las entrevistas con los estudiantes, y esta información se ha empleado para el análisis. La primera columna de la Tabla 4 presenta los códigos o temas asociados a diferentes partes de la entrevista. Los códigos se generan en base a la interpretación de las respuestas y sirven como representaciones de una variedad de temas. En la segunda columna presentamos la frecuencia de cada código, según la cual, un código específico o tema ha sido asignado a algunas respuestas más de una vez.

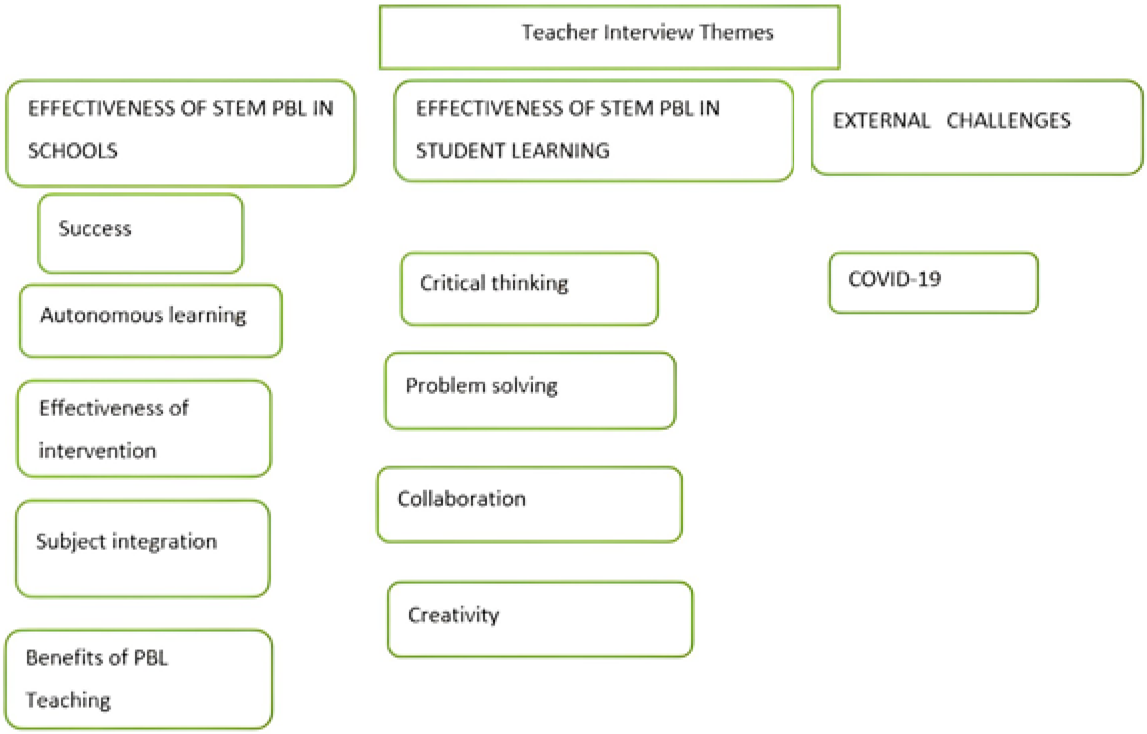
Tabla 4. *Temas extraídos de las entrevistas a los estudiantes.*

| THEME | TEACHERS | STUDENTS |
|---|---|---|
| Autonomous learning | With the PBL pedagogy, teachers viewed themselves as facilitators. One teacher observed that students were able to "*convert their knowledge of various subjects into a practical application"* | Students took responsibility for their own prototype. One student noted that there was limited teacher intervention in the design process, stating *"limited output and working* in groups without the "teacher helping us to do it." |
| Critical thinking | One of the teachers found that *STEM PBL improves students critical thinking, which improves their learning"* and the *snail car* construction activity expanded the students' scope of critical thinking. | Students also mentioned that with STEM PBL *"I am capable of making connections outside of my classroom, and the experiment connected me to real-world problems."* |
| Subject integration | STEM is successful across the different subjects. STEM is successful across the different subjects. According to one teacher "*a real-life context that gave the students freedom to think for themselves; practical and interactive aspects; and a good balance across all STEM subjects?* | Another student commented on the effectiveness of STEM as an interdisciplinarity "*I learned to convert all knowledge with different subjects into a practical ordinated application"* |
| Collaboration | As can be seen in this response from a teacher, collaboration is effective "*collaboration became easier as students became more familiar with each other."* | STEM PBL facilitates effective collaboration "*working in teamwork and building a prototype to achieve the required objectives."* |

### 7.4.2. **Análisis de los datos obtenidos de las entrevistas con los profesores**

Durante la entrevista, hemos preguntado una serie de preguntas abiertas sobre los beneficios potenciales de la educación STEM para el desarrollo de habilidades de pensamiento crítico. Además, hemos alentado a los profesores a compartir sus mejores prácticas durante el experimento STEM (ver Apéndice 22 en el documento de tesis). Las preguntas que se les hicieron a los profesores estaban relacionadas con tres temas: la efectividad del ABP en asignaturas STEM en el instituto, la efectividad del ABP en asignaturas STEM en el aprendizaje de los estudiantes y retos externos. El contenido de estos temas surgió durante el análisis de las entrevistas. La Figura 2 es un resumen de los temas claves identificados durante las entrevistas con los profesores.

**Figura 2.** *Temas extraídos de las entrevistas a los profesores.*




**Fuente:** *Elaboración propia*

## 6.5. DISCUSIÓN GENERAL Y CONCLUSIÓN DEL ESTUDIO 2

Los temas principales en estas entrevistas se centraron en la eficacia del ABP en asignaturas STEM y en el desarrollo de las habilidades de pensamiento crítico. De forma notable, la introducción del ABP en asignaturas STEM potenció habilidades del siglo XXI, a juicio de los participantes en las entrevistas.

Concretamente, los estudiantes manifestaron que disfrutaron de la actividad práctica, en la que pudieron construir un objeto como solución a un problema del mundo real. También mencionaron de forma notable la energía limpia y la sostenibilidad, y desarrollaron habilidades de pensamiento crítico, así como otras habilidades del siglo XXI necesarias para la preparación universitaria, uno de los objetivos del Ministerio de Educación de EAU (MOE, 2016).

Por su parte, los profesores observaron el desarrollo de habilidades del siglo XXI conforme iban progresando en la creación del prototipo. Esto ocurrió sobre todo durante la fase de intervención, cuando los profesores detectaron una mejora en las habilidades de pensamiento crítico de los estudiantes en el grupo experimental. Además, indicaban un incremento importante en el nivel de motivación de los estudiantes, después de que sus habilidades se vieran reforzadas.

De acuerdo con las respuestas de las entrevistas con los estudiantes y los profesores, está claro que el ABP en asignaturas STEM es particularmente efectivo para enseñar a la generación del presente. El enfoque de ABP para el aprendizaje implica que los estudiantes investiguen, tomen decisiones, diseñen, y concluyan con un producto basado en retos. En el ABP aplicado a asignaturas STEM, los proyectos son la piedra angular de las actividades de diseño ingenieril.

Por tanto, la respuesta a la pregunta de investigación de este estudio, "¿Cómo puede el ABP de STEM promover el aprendizaje efectivo?", nos lleva a determinar que el ABP fomenta un ambiente cautivador y efectivo al incorporar aplicaciones de la vida real. A través de la integración de actividades prácticas, tales como la construcción de un *Snail Car*, los estudiantes se involucran activamente en el proceso de aprendizaje. Los estudiantes comprenden la relevancia y aplicabilidad de lo que aprende cuando aplican la teoría a un contexto de la vida real. La construcción y perfeccionamiento del *Snail Car* motiva a los estudiantes a trabajar en ello, movidos por el entusiasmo y el reto de la tarea. Los estudiantes se sumergen en el proceso de resolución de problemas, pensamiento crítico, y trabajo en equipo, lo cual potencia aún más su dedicación. Por último, el proyecto de *Snail Car* muestra que los ambientes de aprendizaje cautivadores y significativos pueden contribuir al compromiso de los estudiantes y la efectividad del aprendizaje.

# 8. DISCUSIÓN GENERAL Y CONCLUSIÓN

## 8.1. DISCUSIÓN DE LOS RESULTADOS

En lo que concierne al estudio cuantitativo (**Estudio 1**), se plantearon dos hipótesis:

H1. El interés STEM de los estudiantes que reciban la intervención ABP será significativamente diferente de aquellos que reciban la instrucción tradicional, siendo los primeros quienes muestren un interés significativamente mayor por asignaturas STEM.

H2. Se encontrarán diferencias estadísticamente significativas en las habilidades de pensamiento crítico, siendo éstas mayores en aquellos estudiantes que reciban la intervención de ABP en asignaturas STEM en comparación con los que reciban la instrucción tradicional en STEM.

Respecto a la primera de estas hipótesis, el uso del IIR en la Encuesta de Semántica STEM mostró que el grupo experimental, cuyos participantes estuvieron expuestos al ABP, se inclinaron significativamente por trabajos en matemáticas y ciencia. El grupo control demostró un IIR bajo en relación con la ciencia y su importancia para sus futuras profesiones. El grupo experimental mostró un mayor interés por carreras en ciencia con respecto al grupo control. Además, el grupo experimental expresó la relevancia de las disciplinas STEM y el ABP para sus posibles carreras. El IIR indicó que el grupo experimental tuvo un nivel de competencia significativo en la habilidad de trabajo colaborativo.

Por el contrario, el grupo control tuvo dificultades en matemáticas y mostró un bajo interés por carreras en ciencia, enfatizando así el impacto crucial del ABP en el fomento del interés por STEM. La hipótesis apoya que tanto el enfoque de enseñanza tradicional como el de ABP influyen sustancialmente el interés por STEM y el desarrollo de habilidades del siglo XXI. El ABP ha surgido como un catalizador relevante, potenciando el interés por STEM y proporcionando a los estudiantes habilidades esenciales del siglo XXI. En contraste, el método de enseñanza tradicional redujo aparentemente la preferencia por carreras STEM en el grupo control. Estos hallazgos están en línea con los del estudio de Shaw (2018) sobre la interacción entre el ABP y la educación STEM, especialmente en la promoción de habilidades esenciales del siglo XXI, tales como la colaboración, la comunicación, la creatividad, y el pensamiento crítico. El autor enfatizó que la combinación de STEM y el ABP es un método robusto para cultivar estas habilidades fundamentales. Además, Rehman et al. (2023) demostraron que el ABP tiene un impacto positivo sustancial en la capacidad de los estudiantes para colaborar y en su nivel de compromiso activo. Amelia y Santoso (2021) proporcionaron evidencia adicional para respaldar estos hallazgos, mostrando que el ABP no solo mejora las habilidades del siglo XXI en asignaturas STEM, sino que también refuerza habilidades en comunicación, colaboración, pensamiento crítico, y resolución creativa de problemas.

Respecto a la segunda hipótesis, las respuestas obtenidas en el Test de Pensamiento Crítico de Watson y Glaser proporcionaron percepciones significativas sobre la influencia del ABP en las habilidades de pensamiento crítico de los estudiantes. Una clara distinción surgió entre el grupo experimental y el grupo control; el primero mostró mejoras en sus habilidades de pensamiento crítico. De forma significativa, estos estudiantes demostraron una mejora sustancial en varios aspectos del pensamiento crítico, incluyendo la capacidad para detectar suposiciones, reconocer interferencias, comprender información compleja, sacar conclusiones lógicas, y analizar argumentos de forma crítica. Por el contrario, el grupo control, cuyos participantes no estuvieron expuestos al ABP, sólo presentaron una mejora marginal en sus habilidades de pensamiento crítico. Esta clara distinción resalta el impacto significativo del ABP en la mejora de las habilidades de pensamiento crítico. Los resultados estadísticos son consistentes con la hipótesis de investigación, respaldando la idea de que la instrucción de ABP en asignaturas STEM mejora las habilidades de pensamiento crítico de los estudiantes en comparación con los métodos tradicionales de enseñanza. Las puntuaciones del pretest y postest muestran mejoras significativas en las habilidades de pensamiento crítico del grupo experimental después de la intervención, apoyando aún más la hipótesis. Además, los estudios de Eldiva y Azizah (2019), Insani et al. (2018), Issa y Khataibeh (2021), Terada (2021), y McDowell (2022), empleando el ABP, detectaron mejoras significativas en las habilidades de pensamiento crítico. Por su parte, Terada (2021) descubrió que los estudiantes presentaban una comprensión más profunda sobre temas complejos, niveles más altos de pensamiento analítico (Issa & Khataibeh, 2021), y mejores habilidades de solución de problemas (McDowell, 2022). Estos hallazgos enfatizan los logros de la instrucción ABP en STEM, confirmando su capacidad para mejorar las habilidades de pensamiento crítico de los estudiantes.

Por su parte, el estudio 2, de naturaleza cualitativa, parte de una pregunta de investigación clara que permite una exploración de los aspectos multifacéticos que contribuyen a un ambiente de aprendizaje enriquecido. Esta es la siguiente: *"¿Cómo puede el ABP promover el aprendizaje efectivo?"*.

El ABP, cuando se implementa de forma efectiva, promueve mayor compromiso, colaboración y pensamiento crítico en los estudiantes. En primer lugar, cultiva la participación activa a través de la inmersión en retos del mundo real, alentándoles a aplicar el conocimiento teórico a situaciones prácticas. Este enfoque despierta la curiosidad y la motivación intrínseca, impulsando una comprensión más profunda de los conceptos. En segundo lugar, al ABP promueve habilidades de colaboración y comunicación, ya que los estudiantes trabajan juntos para resolver problemas, fomentando así un sentimiento de trabajo en equipo y responsabilidad compartida. En tercer lugar, enfatiza el desarrollo de habilidades de pensamiento crítico al exigir a los estudiantes que analicen, sinteticen y evalúen la información, permitiéndoles abordar temas complejos con creatividad e ingenio. Además, el ABP incentiva la autonomía y el auto-aprendizaje, empoderando a los estudiantes para que lideren su educación y desarrollen habilidades esenciales para un aprendizaje de por vida. Por lo tanto, la pregunta de investigación profundiza en cómo el ABP crea un ecosistema de aprendizaje efectivo al incluir la dedicación, la colaboración, el pensamiento crítico, y la autonomía como componentes vitales del proceso educativo.

El ABP también facilita el aprendizaje. Yuliani y Lengkanawati (2017) examinaron varios métodos instructivos que promueven el aprendizaje independiente, uno de los cuales era el ABP. Según estos autores, el ABP potencia la autonomía del aprendiz (incluyendo auto-instrucción, auto-dirección y aprendizaje de auto-acceso) y la individualización de la instrucción en cada fase de las actividades de ABP (incluyendo la planificación, la implementación y el seguimiento). Tal como apuntó también ChanLin (2008), el ABP es un método efectivo para introducir a los estudiantes al aprendizaje auto-dirigido. ChanLin (2008) observó que los estudiantes mostraban mejor aprendizaje cuando se involucraban en actividades basadas en páginas web que promovían la auto-dirección, el razonamiento profesional, y la auto-determinación.

Stefanou et al. (2013) analizaron estrategias de auto-regulación en un contexto de ABP para determinar si había diferencias en los resultados de auto-regulación entre los estudiantes. La colaboración, el pensamiento crítico y la metacognición tuvieron más prevalencia en ambientes ABP en los estudiantes. Además, Stefanou et al. (2013) detectaron que los estudiantes tenían más probabilidades de percibir que sus instructores apoyaban el pensamiento independiente y la acción en cursos basados en proyectos.

En definitiva, el éxito del ABP ha sido demostrado en varios estudios, cuyos hallazgos indican que las habilidades de pensamiento crítico se pueden desarrollar cuando el ABP se incorpora a un currículum STEM. Los modelos de ABP aplicados en asignaturas STEM han mostrado su efectividad para mejorar el desarrollo del pensamiento crítico (Rochim et al., 2021).

Por su parte, Sarwi et al. (2021) y Noble et al. (2020) recomiendan a escuelas STEM adoptar enfoques de ABP. El ABP puede integrar eficazmente asignaturas STEM en el aula (Navy & Kaya, 2020). Además, Rasul et al. (2016) detectaron que el ABP en la educación STEM "potencia las habilidades del siglo XXI de los estudiantes al proporcionar experiencias de la vida real en la solución de problemas auténticos. Rochim et al. (2017) demostraron de forma consistente que la integración de modelos de ABP en asignaturas STEM mejora los resultados de aprendizaje en las áreas STEM. Igualmente, Markula y Aksela (2022) establecieron la efectividad del ABP en la educación científica. Noble et al. (2020) también identificaron que el ABP puede incrementar el interés y la actitud de los estudiantes por asignaturas STEM. La literatura académica citada evidencia que el ABP ha demostrado ser un método particularmente efectivo para la integración de STEM en el aula. Este fenómeno también ha sido observado en esta investigación, durante el experimento con el *Snail Car*. En este proceso, los profesores juegan un papel limitado, permitiendo a los estudiantes liderar su aprendizaje.

Por otro lado, el ABP ayuda a fomentar el desarrollo de habilidades de pensamiento crítico en los estudiantes. Estos hallazgos son consistentes con la evidencia empírica presentada en esta investigación, la cual indica que los estudiantes pudieron resolver problemas y retos en el mundo real de forma efectiva. También demostraron un incremento en su capacidad para evaluar de forma crítica soluciones potenciales antes de sacar una conclusión durante la construcción de su *Snail Car*. Utilizando situaciones en ABP, Aranguiz et al. (2020) observaron que esto motivó a los estudiantes a reflexionar sobre el pensamiento crítico y a abordar problemas de sostenibilidad a los que se enfrenta hoy día la sociedad. Rochmahwati (2015) afirma que el ABP potenció las habilidades de pensamiento crítico en estudiantes de TEFL, mientras que Wibowo et al. (2018) descubrió que el ABP impulsó las habilidades de pensamiento crítico en estudiantes de ciencias. También se ha demostrado que el uso del ABP incrementa las habilidades de pensamiento crítico (Sasson et al., 2018). Además, Eldiva y Azizah (2019) observaron que el ABP no sólo mejoró las habilidades de pensamiento crítico, sino que también tuvo un impacto positivo en los estudiantes con necesidades especiales. Igualmente, Alawi y Soh (2019) apoyan la efectividad del ABP en el desarrollo del pensamiento crítico en la educación STEM. Los estudiantes que participaron en la intervención de ABP en asignaturas STEM mostraron altos niveles de pensamiento crítico (Eja et al., 2020). Trisdiono et al. (2019) concluyeron que los modelos integrados y multidisciplinarios de ABP contribuyen significativamente al desarrollo de habilidades de pensamiento crítico y trabajo en equipo en estudiantes de primaria. En su estudio, Jusmaya y Efyanto (2018) encontraron que el ABP potenció las habilidades de pensamiento crítico de los estudiantes. Mutakinati et al. (2018) afirman que los estudiantes desarrollaron pensamiento crítico con la incorporación del ABP en la educación STEM. Uno de los principales resultados del ABP de STEM es el desarrollo de habilidades de pensamiento crítico y comunicación, como apuntan Oktavia y Ridlo (2020). En su estudio, estos autores encontraron que los estudiantes con altos niveles de habilidades de pensamiento crítico mostraron la capacidad de analizar argumentos, aquellos con niveles moderados alcanzaron los aspectos simples de explicación, y aquellos con niveles bajos solamente se centraron en responder a las preguntas. Los autores concluyeron que el método de STEM utilizado en el ABP motivó a los estudiantes a incrementar su comunicación verbal y sus habilidades de pensamiento crítico conforme abordaban los retos. Además, los hallazgos de este estudio son consistentes con aquellos de estudios previos que han demostrado que el ABP puede potenciar las habilidades de pensamiento crítico a través del desarrollo de habilidades de resolución creativa de problemas.

El ABP también puede proporcionar un ambiente de aprendizaje efectivo para la colaboración. Tal y como concluyeron Al Rasyid y Khoirunnisa (2021), el ABP ha demostrado su efectividad en el desarrollo de habilidades de colaboración sólidas, superando los referentes predefinidos para cada indicador de habilidad de colaboración. Otro estudio realizado por Papanikolaou y Boubouka (2010) analizó la eficacia de guiones colaborativos para promover conocimiento metacognitivo en aprendizaje electrónico basado en proyectos. En todo el diseño y las fases de evaluación del estudio, estos autores observaron que los estudiantes siguieron un guion cooperativo distintivo, el cual les permitió reflexionar tanto individual como socialmente. El estudio de Weber (2019) exploró la efectividad de la integración de tecnologías colaborativas en el ABP. El estudio consistió en enseñar herramientas colaborativas a los estudiantes, los cuales pudieron articular sus procesos colaborativos durante las sesiones y demostraron una probabilidad menor de involucrarse en conflictos o quejarse de sus compañeros. Se ha concluido a partir de los resultados que es esencial enseñar habilidades colaborativas a los estudiantes y dotarles de herramientas colaborativas (Weber, 2019). Estudios previos (Alharbi et al., 2018) han identificado barreras para la colaboración. Este problema ha sido abordado con el uso del enfoque de ABP, el cual ha dado resultados favorables. Además, el ABP ha mostrado su efectividad para potenciar resultados colaborativos *online* (García, 2016). En un entorno virtual, el autor encontró que el ABP puede incrementar significativamente el aprendizaje. En su estudio, Trisdiono et al. (2019) sugirieron que el ABP facilitaba la colaboración, mientras que Markula y Aksela (2022) concluyeron que el ABP promueve explícitamente la utilización de la colaboración para la investigación, la presentación de hallazgos, y la reflexión sobre los hallazgos. Igualmente, de la Torre-Neches et al. (2020) subrayaron la importancia del ABP para la promoción de la participación y dedicación de los estudiantes. Por otra parte, también se ha analizado el impacto del ABP en las habilidades de colaboración de los estudiantes con inglés como segundo idioma (Andriyani & Anam, 2022). Considerando la literatura mencionada, el presente estudio ha encontrado resultados similares de los efectos positivos del ABP colaborativo a través del reto de construir un *Snail Car*.

En esta investigación, se ha detectado que los estudiantes pudieron completar objetivos específicos y claramente definidos dentro de un marco social, al estar motivados y entusiasmados. Igualmente, las entrevistas con los estudiantes revelaron que sus habilidades colaborativas se extendieron más allá de su asignación al grupo experimental o control. A través de la delegación efectiva de tareas, aprovechando las ideas de cada uno, y completando las tareas juntos, desarrollaron habilidades de colaboración. Las contribuciones de iguales demuestran la importancia del aprendizaje y la colaboración para el éxito del experimento con el *Snail Car*. Además, los estudiantes crearon un grupo de WhatsApp para facilitar su comunicación y colaboración.

En consonancia con los hallazgos de los estudios consultados y los datos cualitativos obtenidos de las entrevistas con los estudiantes y los profesores, el ABP demuestra en el contexto de investigación su capacidad para potenciar el pensamiento crítico, mejorar la colaboración y promover el aprendizaje autónomo. Esta investigación sugiere que el ABP influye positivamente en las habilidades de pensamiento crítico. A través del ABP, se reta a los estudiantes a pensar de forma crítica y a analizar y resolver problemas complejos. A través de la dedicación activa a enfrentar desafíos del mundo real, los estudiantes adquieren una comprensión más completa de la materia. Además, los datos cualitativos recopilados tanto de los estudiantes como de los profesores respaldan la idea de que el ABP promueve la colaboración. Los proyectos de ABP requieren que los estudiantes trabajen en equipos, intercambien ideas, compartan recursos, y negocien tareas. La creación de ambientes cooperativos facilita la comunicación, la colaboración y el desarrollo de habilidades sociales y emocionales.

Por otro lado, el ABP está en línea con la teoría del desarrollo cognitivo de Piaget y el énfasis del constructivismo en la construcción de conocimiento a través de la experiencia (Mcleod, 2018). Así, el ABP facilita el compromiso de los estudiantes con el proceso de aprendizaje. Se ha observado que el ABP proporciona a los estudiantes experiencias de aprendizaje cautivadoras y relevantes al enfocarse en principios y conceptos científicos, involucrándolos en actividades significativas de solución de problemas, y dotándoles de autonomía para construir conocimiento y crear productos de forma independiente, según los hallazgos de la investigación. Sin embargo, el ABP requiere un diseño cuidadoso, y el pensamiento crítico juega un papel crucial en la motivación de los estudiantes. Los contextos de ABP deben ser auténticos, para permitir que los estudiantes expresen sus opiniones, ofreciéndoles elección, y para que resuelvan problemas complejos. Además, este enfoque estimula la motivación y el interés de los estudiantes, con el uso de actividades de aprendizaje realistas. En esta investigación, se ha observado que el ABP proporciona un ambiente para que los estudiantes se involucren en un aprendizaje efectivo. Conforme los estudiantes trabajan de forma colaborativa hacia un objetivo común, esta estrategia les permite aprender tanto contenidos como habilidades del siglo XXI.

## 8.2. CONTRIBUCIÓN DE LA INVESTIGACIÓN

La investigación en ABP de STEM puede ser un método efectivo para evaluar el impacto de este enfoque en el interés de los estudiantes por asignaturas STEM y sus capacidades para desarrollar habilidades de pensamiento crítico. Aprender más sobre el ABP aplicado a asignaturas STEM ofrece a los docentes y las familias una comprensión más profunda de su efectividad y credibilidad, así como la consideración de factores importantes para garantizar el desarrollo adecuado de habilidades y cualidades en los estudiantes. Además, esta investigación aborda las carencias de estudios previos acerca del fomento del pensamiento crítico a través del ABP en EAU. Este estudio difiere de otras investigaciones en cuanto a su enfoque único sobre métodos de investigación. En este trabajo, a los estudiantes se les pidió que construyeran prototipos que pudieran ser aplicados en situaciones de la vida real, proporcionando una representación auténtica de ABP. Aparte de explorar los matices del ABP, este estudio presenta un análisis preciso de cómo se puede implementar el ABP en el aula. Igualmente, los hallazgos de la investigación y el marco de características claves que se han desarrollado como resultado pueden ser de utilidad tanto para profesores como para investigadores. Por otra parte, los resultados de esta investigación pueden ayudar en la formación de nuevos docentes para que sean capaces de incorporar de forma efectiva el ABP en su docencia.

## 8.3. LIMITACIONES

A lo largo del proceso de investigación, las restricciones por COVID-19 presentaron retos importantes, los cuales tuvieron un impacto en la construcción del *Snail Car*. Se implementaron varias mediciones esenciales para garantizar la participación de los estudiantes. Los requerimientos incluyeron la obtención de aprobación por parte de la dirección y las familias, el cumplimiento estricto de los protocolos de COVID-19, y la organización con profesionales sanitarios para realizar PCRs de COVID-19 semanales en los estudiantes y los profesores.

El método de muestreo empleado en esta investigación hizo imposible la asignación automática. La falta de asignación automática puede haber generado un sesgo debido a la eliminación de aleatorización. La razón de esto es que todos los chicos de nivel de 1º de Bachillerato del instituto de formación profesional fueron incluidos en estudio. Por consiguiente, no se establecieron criterios específicos para los chicos de nivel de 1º de Bachillerato, ya que fueron seleccionados en base a los objetivos de la investigación. También existen limitaciones en este trabajo con relación a la asignación de los grupos control y experimental. Dado que los chicos de nivel de 1º de Bachillerato estaban matriculados en cursos STEM, no hubo ningún criterio predeterminado de asignación. Dividimos a los chicos entre el grupo control y el grupo experimental sin considerar su rendimiento académico en estas asignaturas STEM. Esto también genera una limitación, ya que no existen criterios específicos para los dos grupos. El enfoque de muestreo intencional de este estudio podría ser el causante de esta limitación. Esta investigación también tuvo la limitación de que no se realizó un pre-test de la Encuesta de Semántica STEM.

Asimismo, debido a las limitaciones y la indisposición de los estudiantes para realizar entrevistas por Zoom, no fue posible entrevistar al número exacto de estudiantes seleccionados. Por tanto, sólo algunos estudiantes pudieron participar en el proceso de entrevistas. Aunque este estudio ha demostrado el impacto positivo que el ABP aplicado a asignaturas STEM puede tener en las habilidades de pensamiento crítico, un tamaño de muestra mayor y entrevistas presenciales podrían proporcionar datos más relevantes sobre el proceso.

## 8.4. CONCLUSIÓN

Este estudio ha analizado el impacto de un ABP en el pensamiento crítico. Según los resultados de este trabado, el ABP debería ser integrado en asignaturas STEM (Asghar et al., 2012; Han et al., 2016), para que sean lideradas por los estudiantes, así como en disciplinas STEM, para que los estudiantes puedan establecer asociaciones y retener información.

Sobre el primer objetivo, hemos determinado cómo el ABP afecta el interés de los estudiantes por asignaturas STEM. El ABP ha contribuido al interés de los estudiantes por asignaturas STEM. Para determinar si al ABP afecta la dedicación de los estudiantes por STEM, hemos comparado los niveles de interés entre el grupo control y el grupo experimental. El análisis de la Encuesta de Semántica STEM reveló diferencias notables entre el grupo experimental, que recibió la instrucción de ABP, y el grupo control, que recibió la instrucción tradicional. El grupo experimental mostró un mayor interés en asignaturas STEM y una mayor preferencia por carreras STEM. En esta investigación, hemos demostrado que el ABP puede potenciar el interés de los estudiantes por asignaturas y STEM carreras en estas áreas. El incremento en el interés de los estudiantes por asignaturas STEM, como ha mostrado la Encuesta de Semántica STEM, evidencia la efectividad de la instrucción de ABP.

En el segundo objetivo, hemos analizado el impacto de la instrucción de ABP de STEM en el desarrollo de habilidades de pensamiento crítico en los estudiantes, considerando los cambios en sus habilidades de pensamiento crítico antes y después de las intervenciones de ABP. Se observó que los estudiantes que participaron en la instrucción de ABP mostraron una mejora significativa en las habilidades de pensamiento crítico en comparación con los estudiantes que recibieron la instrucción tradicional. En consecuencia, el ABP juega un papel importante en el fomento e incremento de las habilidades de pensamiento crítico de los estudiantes en las áreas STEM.

El tercer objetivo de esta investigación reconoce que el ABP puede crear aprendizaje efectivo para los estudiantes en disciplinas STEM desde la perspectiva de los profesores y los estudiantes.

En conclusión, esta investigación ha podido dar respuesta de manera efectiva a los objetivos definidos en la misma, al tiempo que puede sentar las bases para un cambio en el modelo curricular y en los métodos de enseñanza y aprendizaje de las asignaturas STEM.

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